EXPERIMENTAL SCIENCE

Book III

EXPERIMENTAL SCIENCE IN SCHOOL

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BOOK III.

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PREFACE

MANY science books have been written, well adapted for Secondary and Central Schools, with their advantages in laboratory accommodation and science material.

The aim of the present volumes is to furnish a science course for Elementary and other Schools, where usually all the teaching must be done in the ordinary class-rooms with limited apparatus. The experiments included are those which can be carried out without costly apparatus; and encouragement has been given to boys not only to make their own models, but to utilize and adapt any spare material that may be available.

The course is concentric to a large extent, and divided into three books, suitable for boys from eleven to fourteen years of age.

Correlation with mathematics and handicraft has been carried out wherever possible, and everyday experiences and phenomena frequently introduced to illustrate some scientific point or principle.

A chapter on model-making has been placed at the end of the book, but this should be consulted early in the course, so that much of the material needed for a model can be prepared at the Manual Centre before the lesson on the model itself is given.

F. L.
R. J. S.

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EXPERIMENTAL SCIENCE IN SCHOOL

SECTION I.—GENERAL PHYSICS

CHAPTER I

MEASURING INSTRUMENTS

1. **Measurement.**—In Book I. various methods of measuring distances and lengths were given, and with the aid of the ordinary scale ruler you were shown how the results could be *estimated* with fair accuracy to the hundredth part of an inch. But in actual life there are certain kinds of measurement which have to be determined, which cannot be made by the direct use of the ruler alone. In this chapter you will be shown some methods of measurement which will give accurate results where a ruler would fail.

2. **Callipers.**—Callipers are frequently used in both the workshop and the science laboratory to measure "inside" and "outside" diameters and thicknesses.

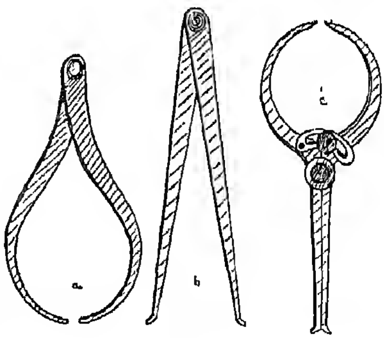


FIG. 1.

Fig. 1 shows three of the ordinary forms of the

instrument, which is something like a pair of compasses with bent legs.

(*a*) Is for outside measurements (*e.g.*, diameters of cylinders).

(*b*) Is for inside measurements (*e.g.*, the bore of a tube).

(*c*) Is a combination of (*a*) and (*b*), which can be used for both inside and outside measurements.

NOTE.—*Instructions are given in Chapter XXX. for making a pair of callipers.*

EXPERIMENT 1.—**To measure the diameter of a penny.**

Open the legs of the "outside" callipers until nearly wide enough for the widest part of the penny to pass through. Now pull the penny gently through, allowing the legs of the callipers to open just *sufficiently* for the passage of the coin. Every diameter of a penny should be of equal length; this can be tested by turning the penny round a little and passing it through again. When you are satisfied that the greatest width of the penny passes through *but touches each leg lightly*, place the callipers down on the ruler and measure the distance between the points.

In a similar manner, measure the diameter of a cylinder of wood, a glass tube, and a marble.

EXPERIMENT 2.—**To measure the bore of a tube.**

Slip the "inside" callipers well into the tube with the legs closed, and open them until the ends touch the tube at points exactly opposite. Holding the callipers quite still, rotate the tube a little. Adjust the callipers, if necessary, until you are satisfied that they are touching the sides at the widest place.

Place the callipers on the ruler and measure the distance between the points.

Measure in the same way the internal diameter of a test-tube, the neck of a vase, a piece of iron pipe, and a ring.

3. **Tube Gauge.**—A more reliable instrument than the callipers for measuring the bore of a tube can easily be made from cardboard and squared paper.

EXPERIMENT 3.—On a sheet of squared paper (divided into centimetres and millimetres) draw a right-angled triangle, making the base 2 cms. long and the height 10 cms. (see Fig. 2). (The base and perpendicular should be drawn on the *thick* lines marking the centimetres.) Draw lines across the triangle, parallel to the base, at distances of 5 mms. apart. These will divide the height into 20 equal parts.

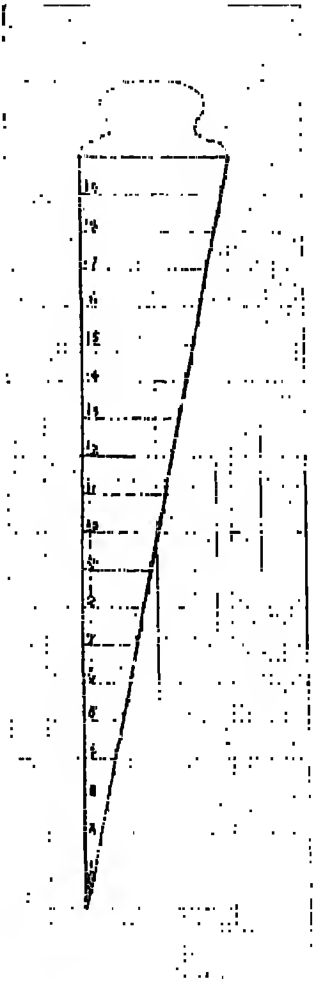


FIG. 2.

Look at the small triangle which is shaded in the figure. It is **exactly** the same **shape** as the large triangle, but of **different size.**

Since the height is $\frac{1}{20}$ of the large height, the base will be $\frac{1}{20}$ of the large base. $\frac{1}{20}$ of 2 cms. $= \frac{1}{10}$ cm., or 1 mm.

Arguing in the same way, you will see that the other bases will be 2 mms., 3 mms., 4 mms. . . . . up to 20 mms., or 2 cms.

Mark the lines 1, 2, 3, 4, ... as shown.

Gum your squared paper on a piece of thin cardboard, and when dry, cut out the triangle, leaving a piece at the top for a handle (dotted in Fig. 2).

EXPERIMENT 4.—**To measure the bore of a tube with the tube-gauge you have made.**

Push the fine end of the gauge into the tube, keeping the vertical side against the side of the tube. When the sloping side touches and the gauge will not move sideways, rotate the tube a little. If it still touches, the horizontal line which is level with the top of the tube is the diameter.

If this line happens to be one of the lines you have drawn and numbered, the number will give you the diameter in millimetres.

If the gauge rests between two lines, you can estimate, by means of the lines on the squared paper, the decimal of a millimetre.

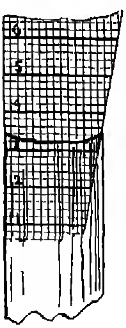


FIG. 3.

For example, in Fig. 3, showing part of the gauge, the diameter is 13·4 mms., or 1·34 cms.

4. **The Vernier.**—A ruler will give you an accurate measurement in either inches or centimetres to one place of decimals (*i.e.*, in tenths).

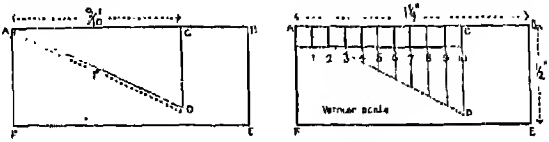
You have been shown how to estimate the second decimal place in case the end of the object measured does not coincide with a mark on your ruler. The **vernier** is an instrument with which you can

actually measure such small distances accurately instead of merely estimating them.

NOTE.—*The instrument is named after Pierre Vernier, who was born in* 1580.

Construction.—Mark off on a straight edge of a piece of cardboard a distance *exactly* $\frac{9}{10}''$ long.

Divide this into ten equal parts as follows: Draw



a FIG. 4. *b*

CD at right angles to *AB*, and from *A* draw *AD* exactly 1″ long [Fig. 4 (*a*)].

Divide *AD* into ten equal parts, and through each mark draw lines parallel to *CD*, taking great care that each division is as exact as possible. Complete the scale as shown [Fig. 4 (*b*)].

NOTE.—*The thin construction lines can be drawn in pencil, the finished scale* (i.e., *the thicker lines*) *in ink. The pencil lines can then be erased.*

Cut out the rectangle *AB EF*.

Place the vernier scale (as it is called) against your ruler, as shown in Fig. 5. (In the figure the tenths are numbered.)

Each division on your vernier $= \frac{1}{10} \times \frac{9}{10}'' = \frac{9}{100}''$.

Each division on your ruler $= \frac{1}{10}'' = \frac{10}{100}''$.

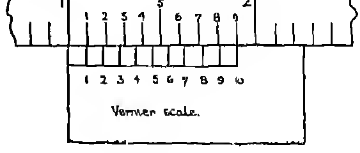


FIG. 5.

Therefore the difference between one division on your ruler and one division on your vernier $= \frac{10}{100}'' - \frac{9}{100}'' = \frac{1}{100}''$.

Can you see from this, that the distance between the division marks numbered 2, 3, 4, etc., on each is $\frac{2}{100}''$, $\frac{3}{100}''$, $\frac{4}{100}''$?

Experiment 5.—**To measure the length of an object, using the vernier.**

(Choose an object that cannot be measured exactly in tenths of an inch.)

Place the vernier against the end of the object with the scale touching the scale on the ruler.

Suppose the end of the object is opposite a point between 3·4″ and 3·5″ (see Fig. 6).

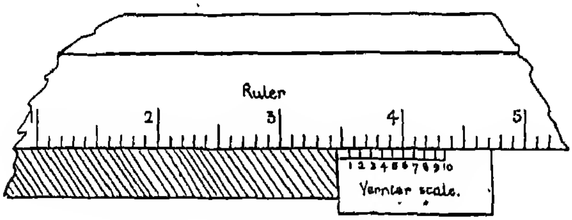


Fig. 6.

Look at Fig. 7, which is an enlargement of the portion of Fig. 6 being considered. The distance AB between the arrows is to be measured. Now, the distance from A to C, where the lines *coincide* $= \frac{6}{10}''$ (= ·6″).

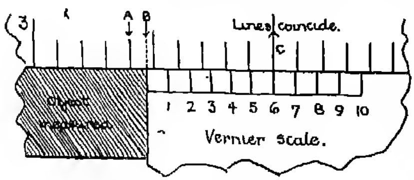


Fig. 7.

From B to C = 6 divisions of the vernier, and each division is $\frac{1}{100}''$ (= ·01″) *less* than $\frac{1}{10}''$.

Therefore from A to $B = \frac{6}{100}'' = \cdot 06''$.

Therefore the length of the object is $3'' + \frac{4}{10}'' + \frac{6}{100}'' = 3\cdot 46''$.

The rule for measuring with a vernier, therefore, is—

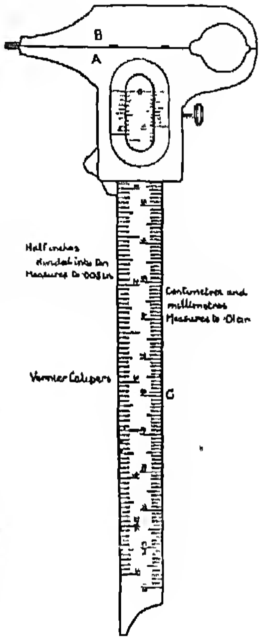


FIG. 8.

(1) Place the vernier against the end of the object and touching the ruler.

(2) The last inch mark before the end of the object **gives the number of inches.**

(3) The last tenth mark before the end of the object **gives the number of tenths.**

(4) The mark on the vernier which coincides with one of the tenths of the ruler scale, **gives the number of hundredths.**

NOTES.—(i.) *A vernier can also be made for a centimetre scale.*

(ii.) *Verniers, such as are sold, are made of metal and attached to scales, so that they slide along. Such a vernier is difficult for a boy to make accurately.*

(iii.) *Special callipers are made with a vernier attached. These are called vernier callipers. The instrument shown in the drawing* (Fig. 8) *will measure accurately to* ·005″ *or* ·01 *cm. The part A slides along the bar C, which is fastened to the end B. The object to be measured is placed between A and B. The vernier is on the part A.*

5. **The Screw Gauge.**—This is the most accurate measuring instrument in common use. As its name suggests, it is based on the screw.

EXPERIMENT 6.—Cut out from paper a right-angled triangle of the dimensions shown in Fig. 9 (*a*).

Draw a thick ink line along the sloping edge, place your pencil down along the 2 cm. side, and roll the paper round the pencil [Fig. 9 (*b*)]. Gum the end down.

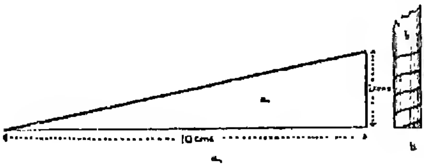


FIG. 9.

This gives you a model of a **screw thread.** Hold your pencil upright and measure the vertical distances between any line and the line above or below it. They are equal in every case. Measure the distances between the threads of a screw in a similar manner. These are also equal to one another.

The distance between one thread of a screw and the next, measured along the screw, is called **the pitch of the screw.**

EXPERIMENT 7.—Make a hole in a piece of $\frac{1}{4}''$ wood. Drive a screw, $1\frac{1}{2}''$ long, into the hole until the point protrudes a little way. Mark the distance it protrudes along the edge of a piece of paper.

Rest the wood on the edge of the bench and give the screw **one complete turn** with the screw-driver. On the same paper, mark the distance it now protrudes. *How far has it gone forward?*

Give the screw four more complete turns and measure the further distance that the screw-point protrudes. Divide the extra length by 4. It should give the same result as that for the first turn measured.

Take the screw out and measure its *pitch* by placing the screw beside a scale ruler. Remember that a wood screw tapers at the point. The result should be the same as the distance moved forward for a complete turn.

For each complete turn of the screw-head, the

point of a screw moves forward a distance equal to the pitch.

Suppose that the pitch of a woodwork screw, $1\frac{1}{2}''$ long, is $\frac{1}{12}''$. If the screw is turned once completely, the point goes forward $\frac{1}{12}''$.

If the head is given—

$\frac{1}{2}$ of a complete turn, the point goes forward $\frac{1}{24}''$;
$\frac{1}{10}$ " " " " $\frac{1}{120}''$.

You can see there are possibilities here for making use of the screw when measurements have to be made which call for extreme accuracy. Let us see how the principle can be used.

EXPERIMENT 8.—Obtain a nut and a bolt (one having an exact number of turns to an inch. A Whitworth $\frac{1}{4}''$ diameter bolt has 20 turns to the inch).

Fit up the apparatus as shown. (*Full directions are given in Chapter XXX.*) A circular metal disc, preferably brass $\frac{1}{16}''$ thick, the circumference of which is divided into 5 equal parts, is soldered to the underside of the head of the bolt, so that when the bottom of the bolt touches the base-board lightly one of the five marks (marked *O*) exactly touches the black line on the upright.

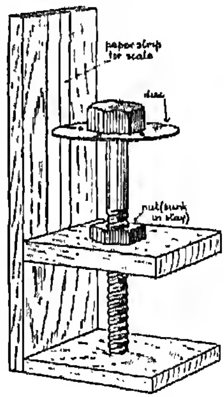
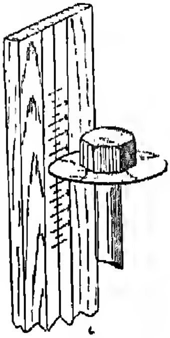


FIG. 10.

Make a mark on the black line at this point, exactly level with the top of the disc. Unscrew the bolt one turn. The mark on the disc will again touch the black line.

Make the next division line on the upright, and continue for 20 turns. (See Fig. 11.)

If your bolt has a **pitch** of $\frac{1}{20}''$, this should give you 1″ exactly. Check this.



Each of these divisions is ·05″ of an inch. Two of them equal ·1″.

Number them in twos, ·1, ·2, ·3, ·4 . . . . 1.

Number the marks on the disc from 0–4, thus showing 5 divisions of the circumference.

If the head of the screw has been given a *complete* number of turns, the distance through which it has risen can be read at once from the scale on the upright. Any fraction over a complete turn must be read from the disc.

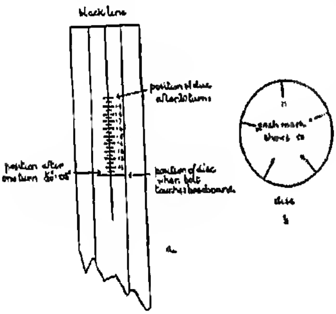


FIG. 11.

One complete turn = a rise of $\frac{1}{20}''$ = ·05″.

Therefore $\frac{1}{5}$ of a turn = a rise of $\frac{1}{100}''$ = ·01″.

So that for every additional mark on the disc to which the head of the screw has been turned beyond the zero mark, you should add ·01″. Let us consider an example.

EXPERIMENT 9.—**To measure the thickness of a metal plate.**

Unscrew the bolt sufficiently to place the metal between the bolt and the base. Screw up again until the end of the bolt just touches the plate lightly.

Suppose ·6″ is the first mark on the black line showing *above* the disc.

Then ·55″ is the first mark *below* the disc, and the thickness of the plate = ·55″ + the fraction of a turn indicated on the disc.

Suppose that the mark 3 on the disc is the nearest to the black line on the upright. This mark represents a distance of ·03″ beyond the zero. [See Fig. 11 (*c*)].

The measurement required must then be ·55″ + ·03″ = ·58″.

NOTES.—(i.) *You can easily see that if we divided each of the* 5 *parts of the circumference into* 10 *smaller equal parts, each tiny fraction of a turn thus marked out would represent a rise in height of* ·001, *so that with a* well-constructed *screw-gauge you could measure the thickness of an object to the thousandth part of an inch.*

(ii.) *Remember that your apparatus is a "home-made" one, and perhaps not quite reliable. But you will understand the principle, and thus know* how *to measure an object accurately.*

Fig. 12 shows you the usual form of a screw-gauge. The scale is marked on the frame, and this is uncovered by the cap as the head of the screw rises. For a complete turn the screw rises 1 mm., and the cap is divided into 100 equal parts, so that by its aid a thickness can be measured to the hundredth part of a millimetre. Considering how small a millimetre is, you will appreciate to how high a degree of accuracy a screw-gauge can measure.

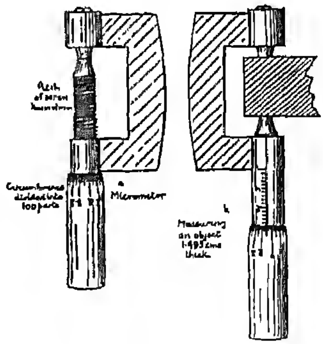


FIG. 12.

In the diagram given, the object measured has a thickness of 14·95 mms. = 1·495 cms.

Chapter II

THE PENDULUM

6. **A Simple Pendulum.**—Tie a light, strong thread, about 40″ long, to a small piece of heavy metal. (A leaden ball is best, but an iron nut will do quite well.) Fasten the other end of the thread to a support, so that the bob (*i.e.*, the metal ball) can swing to and fro quite freely.

This forms a simple pendulum. The point of support is called the centre of suspension; the length of the pendulum is the distance from this point to the *centre* of the bob.

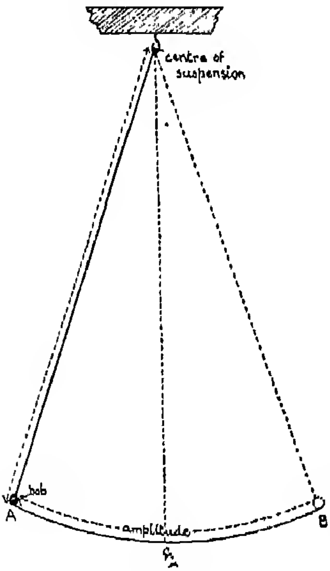


Fig. 13.

When the pendulum swings, the bob describes an arc, and the distance that it travels between the ends of the arc is called the amplitude of the swing.

The time of oscillation, vibration, or swing, is usually taken to mean the time for the *whole* of a to-and-fro movement. It is measured by calculating the time taken by the bob to travel from the lowest point *up* to one side, *back* to

the other side, and then *down* to the lowest point again. An oscillation is thus a double swing.

NOTE.—*The swinging of a pendulum is due to the action of the force of gravity. When the bob is at rest, it is in the lowest position which the thread allows it to reach. To start the pendulum swinging, we pull the bob sideways. This raises the bob slightly, and as soon as we let go, gravity pulls the bob downwards. If the bob were perfectly free, it would fall vertically downwards, but the presence of the string only permits it to take the path along the curve. When it reaches its lowest point, its* momentum (*due to its velocity*) *carries it further and raises it on the opposite side, thus starting a swinging movement which continues for some time.*

7. **Amplitude and Time of Oscillation**—EXPERIMENT 10.—Set up a pendulum about 18″ long, and set it swinging *slightly* by pulling the bob to one side and letting go. Place a mark just below the lowest point, and note the time on a watch (using the seconds hand) when the bob crosses the mark. When the bob passes the mark again *in the same direction*—that is, after a *double* swing—count 1 and so on up to 100.

Repeat the experiment 3 or 4 times, using a longer swing each time. Enter the result in your note-book:

EFFECT OF AMPLITUDE ON TIME OF SWING.

Kind of Swing.	Time of 100 Swings.	Time of 1 Swing.
(*a*) Very short swing (*b*) Short swing (*c*) Longer ,, (*d*) Still longer swing		

You should now be able to show that the results are *very nearly* the same, and that as well as you can judge —the time of swing does not depend on the amplitude.

NOTES.—(i.) *Though the above conclusion is very nearly true, there is, however, a* slight *but* real *increase in time of swing with amplitude. This difference becomes noticeable when the amplitude is* very *great.*

(ii.) *It should be a very simple matter for a boy to prove for himself, by experimenting with pendulums of exactly the same length but with bobs of different weights, that the* time of oscillation *does not depend on the* weight of the bob. *Care must always be taken to measure the length of a pendulum from the point of suspension to the centre of the bob, and not to its lowest point.*

EXPERIMENT 11.—Another method of showing that the time of swing is independent of the amplitude, is to suspend *two* pendulums of equal lengths and similar bobs side by side. Then, taking a bob in each hand, withdraw one to a greater distance than the other. Release them *at the same instant,* but keep your hands still in the same position and you will find that both the bobs will return to the fingers *at the same moment.*

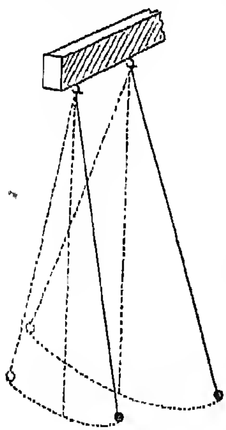


FIG. 14.

8. Length of Pendulum and Time of Oscillation—EXPERIMENT 12.—Using the *same* bob in every case, carry out a set of experiments, employing *a different length of thread in each,* and record the results in a table:

Length of Pendulum.	Time of 100 Swings.	Time of 1 Swing.
4″		
8″		
12″		
16″		
20″		
24″		
36″		

You will have easily noted that the longer the pendulum, the longer the time of swing, but on examining the results closely, you will see that *doubling* the length does not double the time of swing.

What your table should show you is that—

Increasing the length 4 times, doubles the time of swing.

Increasing the length 9 times, trebles the time of swing.

What would be the effect on the oscillations of a pendulum if its length were 25 times the original length?

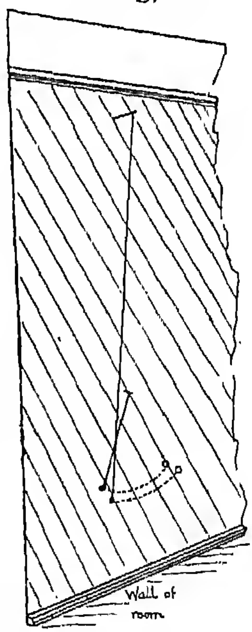


Fig. 15.

Experiment 13.—Test the above results by suspending *two* pendulums, one of which is four times the length of the other, so that the *bobs* are close together. Draw them back and release them together. Prove that they return to the hand together when the shorter pendulum has per-

formed two complete oscillations and the longer pendulum one.

Again, prove that with one pendulum nine times as long as the other, the shorter performs three oscillations to one of the other.

This is expressed as follows:

The time of oscillation of a pendulum varies as the square root of its length.

History of the Pendulum.—Many persons have watched objects swinging to and fro, but it was the famous Italian, Galileo, born in 1564, who first noted the laws which you have been studying in this chapter.

A large lamp, which had just been lit in the cathedral at Pisa, was swinging somewhat vigorously, and Galileo wondered whether the *time of swing* would become shorter as the lamp gradually came to rest. He, therefore, used his pulse-beats to time the swings, and found that each swing of the lamp took the *same number* of pulse-beats, even when it had become very small indeed.

After experimenting at home, he decided to put his discovery to a practical use, and showed how doctors could use a pendulum (whose length could be varied) to test the rate of their patients' pulses. But this was only a step to his great invention of pendulum clocks.

The problem to be solved was how to keep a pendulum swinging. If this could be done, and a pendulum of suitable length made to beat seconds, a timepiece could be constructed. Some force must be applied to the pendulum to give it a little push at exactly the right moment to overcome the friction at the supports and the resistance of the air, which would otherwise stop the swing. The outcome of his experiments, and those of others who followed him, was the "grandfather"

clock. Most of you have seen one, and have also heard its peculiar "tick-tock."

"Grandfather" Clocks.—In these clocks, the "driving force" is obtained by the slow downward movement of a heavy weight. This is attached to a long cord, which is wound over a drum (a metal cylinder) by the turning of a key. The falling of the weight pulls round this drum, and the wheels connected to it, and would do so at a great rate were it not for the check given to it by the **anchor escapement**. (See Fig. 16.) The *escape-wheel* has 30 teeth in its rim, and as it revolves the "anchor" rocks to and fro. With each motion of the "anchor" the wheel advances by one tooth. The "anchor" is also connected to the pendulum in such a way that it keeps in time with it. Thus, the escape-wheel goes round at a definite rate, and by means of cog-wheels causes the second, minute, and hour hands to revolve round the dial and tell us the time.

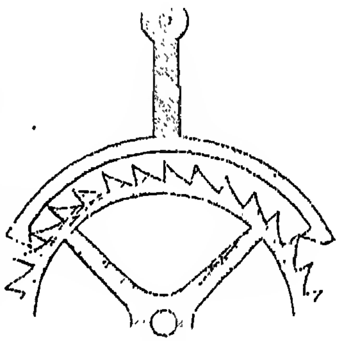


FIG 16.

Regulating a Pendulum Clock.—Suppose a clock "gains" or "loses," *how can it be regulated?* Here the principle mentioned in Paragraph 8 is of use to us, that the time of swing depends on the *length* of the pendulum.

The bob of the pendulum slides along the pendulum-rod, and is supported by a circular nut which screws on to the rod.

You will understand from the lesson on the Screw

Gauge how a very fine adjustment of the height of the bob can be effected by a slight turning of the screw nut.

NOTES.—(i.) *Pendulums made of metal will change in length according to temperature. Special means have to be taken to compensate for this in clocks required for very accurate work.*

(ii.) *In small pendulum-clocks a spring provides the driving force instead of a falling weight.*

SUMMARY OF CHAPTER II.

The Pendulum.

1. The time of swing or oscillation is the time the pendulum takes in travelling from the lowest point until it passes that point again in the same direction.

2. The time of swing does not depend on the amplitude. It is also independent of the weight of the bob.

3. A long pendulum has a slower swing than a short one. The times of swing of two pendulums can be compared by comparing the square roots of their lengths.

CHAPTER III

FORCE

9. **Force and Motion**—EXPERIMENT 14.—Try each of the following:

(*a*) Attach a string to a weight and *pull* it along the table.

(*b*) *Push* the weight by means of a stick.

(*c*) *Attract* a piece of iron by means of a magnet.

(*d*) *Stretch* a catapult and *shoot* a paper ball across the room.

(*e*) *Drop* a ball on the floor.

What is it that produced the motion in each case? The *force* supplied by the hand,—the magnetic *force*,—the *force* of elasticity,—the *force* of gravity.

Whenever you observe anything that is at rest begin to move, you realize that a *force* has acted on it.

But if you tried to *stop* a large boulder rolling down a steep slope, you would have to exert a big effort, and this effort we also call a *force*, and in this sense all *resistance to motion* is force. So, we see, **force produces or stops motion.** Force, however, may be trying to produce motion, but may be prevented by another force. Therefore, we say—

Force is that which *tends* to produce or destroy motion.

One of the most important properties of all bodies is the tendency to "keep as they are,"—if they are at rest, *to remain at rest;* if in motion, *to go on moving in a*

straight line, unless friction, obstacles, or other forces intervene.

A man, travelling in a swift express, partakes of its speed. If the train suddenly stops, the motion of the man continues, and he is thrown violently forward. For the same reason, care must be taken in alighting from a moving bus. Though the feet are checked by contact with the ground, the upper part of the body still moves forward and a fall may result. On the other hand, in *boarding* a moving bus or train, the tendency will be to fall *backward.*

This resistance of a body to change of state, whether of rest or motion, is called **inertia.**

The fly-wheel of an engine is an example of the practical use of inertia. When it is revolving rapidly, the wheel is a storehouse of a considerable amount of energy, which keeps the engine running smoothly, in spite of little defects which would otherwise cause trouble.

You should note, also, that the tendency of a moving body is to continue its motion in a *straight line.* At first this seems untrue, for if we tie a nut to the end of a string and revolve it rapidly, it will continue in its *circular* path for some time. The reason for this is that the hand is *pulling* the string all the time, thereby exerting a force on it. Use a stone in a sling instead, revolve it and then suddenly release one string. Away goes the stone in a straight line at right angles to the string at the moment of release (*i.e.*, along a tangent to the circle).

10. **Action and Reaction.**—We cannot think of a force without thinking also of a body on which it can act, and in most cases we have to consider *two* bodies.

For instance, if a weight is being lifted, we have not only the *weight* itself, but the *person* exerting the force.

Note that the weight is being pulled downward by gravity, and that the upward force must be greater than this.

A *book* lies on the table; the force of gravity is acting on it, but a *resisting* force is being exerted by the *table* sufficient to counterbalance the weight of the book.

Even when a horse pulls along a cart, it is also being pulled back by the cart. We push against a wall, the wall resists; how great this resistance may be we see in the case of a boy who runs violently against it—the reaction is often enough to throw him backward to the ground.

These results are often expressed as follows: **To every action there is an opposite reaction.**

11. **Forces in Equilibrium.**—A door, pushed on both sides by *equal and opposite* forces will not move;

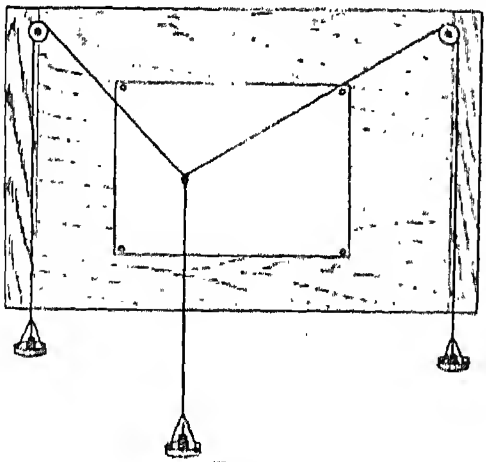


FIG. 17.

that is, two equal and opposite forces destroy the effect of each other. They are said to be in **equilibrium.** It

is possible to have any number of forces, acting at the same point, in equilibrium, but we shall consider only *three* such forces.

EXPERIMENT 15.—Attach two light, easy-running pulley-wheels to a large, upright drawing-board. Tie three flexible cords to a tiny ring, and allow two of them to run freely over the pulleys. Attach scale-pans to each string (see Fig. 17).

Place *equal* weights in the outer pans, and note the position of the inner pan, and the angles between the strings, as gradually increasing weights are placed in it.

Note that for different weights there are different positions of equilibrium.

Place *unequal* weights in the outer pans, and again note the various positions and angles as the weights in the centre pan are altered.

EXPERIMENT 16.—Pin a sheet of white paper behind the strings; place 1 lb. and $1\frac{1}{2}$ lbs. in the outer pans and $1\frac{3}{4}$ lbs. in the centre pan. When the strings have come to rest, draw pencil lines just behind them on the paper. Remove the paper. Fig. 18 (*a*) represents

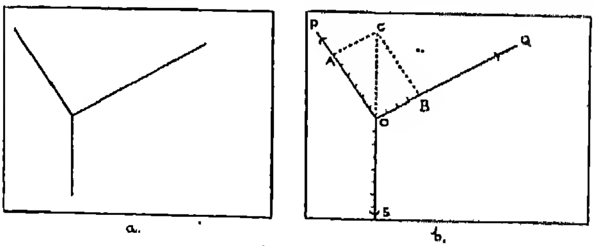


FIG. 18.

the lines as they are drawn. Using a scale of $1'' = \frac{1}{4}$ lb., mark off $OA = 6''$ $(= 1\frac{1}{2}$ lbs.), $OB = 4''$ $(= 1$ lb.), and draw the lines AC and BC parallel to OB and OA respectively.

Note carefully the direction of the diagonal. *It is in line with the downward force.* Measure it. Its length is 7″, representing $1\frac{3}{4}$ lbs.—*the value of the downward force.* [See Fig. 18 (*b*).]

Let us call the three forces pulling the ring *P*, *Q*, and *S*. Their directions are shown by the arrows, their values by marks showing $\frac{1}{4}$ lbs.

Now *P* and *Q* may be said to balance *S* (since the ring is at rest). But *S* could have been balanced by a force acting upward and *represented by OC*.

So *OC* may be regarded as a force equivalent to the two forces *P* and *Q* (that is, able to produce the same result), and *OC*, therefore, is called their resultant. You can always find the resultant of two forces by drawing a parallelogram as we have done in this experiment.

NOTE.—*To obtain absolutely accurate results in the preceding experiments, the weight of the scale-pans and the friction of the wheels should be taken into account. Sufficiently good results to show the principle can be obtained without doing this.*

Example: Supposing that a small cube was being pushed by two forces, *P* equal to 5 lbs. weight, and *Q*

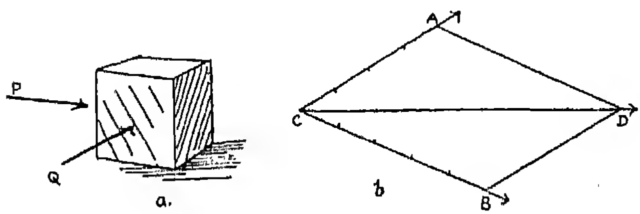


FIG. 19.

equal to 4 lbs. weight, in the direction shown by the arrows [Fig. 19 (*a*)]. *In which direction would the cube be urged forward, and with what force?*

Let us make a separate drawing. Suppose that C [Fig. 19 (b)] represents the centre of the cube. Draw CB in the direction of P, and mark off 5 units (each unit=1 lb.). Then C will be urged in the direction CB by the force P. Draw CA in the direction of Q, and mark off 4 units. C will also be urged in the direction CA, but not so strongly as towards CB. Draw AD parallel to CB; BD parallel to CA, and join CD. Then CD represents the value and direction of the resultant of the two forces P and Q, and the cube will be urged along that line.

NOTE.—*An interesting example of this principle can be seen in the game of cricket. The bowling force is from one wicket to another, but the batsman, by holding his bat at varying angles to the bowling-line and hitting with different degrees of force, can place the ball in many different parts of the field. The ball takes the line which is the direction of the resultant of the forces acting on the ball. Compare, also, the effect of wind on the sails of a ship.*

SUMMARY OF CHAPTER III.

Force.

1. Motion of any kind can only be produced or destroyed by the exertion of a force. **Force** is that which *tends* to produce or destroy **motion**.

2. Equal and opposite forces produce equilibrium.

3. Three or more forces, equal or unequal, can act on a body without moving it. In that case the forces are in *equilibrium*. If the directions and values of two of them are known, the direction and value of the third can be found by constructing the **parallelogram** of forces.

4. The **resultant** of *two* forces acting at a point is a *single* force which, acting at the same point, can produce the same result.

Chapter IV

FALLING BODIES

12. **Speed.**—A boy ran 70 yards in 10 seconds, *what was his speed?* The problem is quite simple to solve—you divide the **distance** traversed by the **time** taken, and the answer gives the **average speed**, for the question does not mention whether the boy kept the same speed throughout. If the rate was constant, then you could say that he had a **uniform speed** of 7 yards per second.

Often the word **velocity** is used instead of speed; but while the latter word means the rate of motion whether in a straight or zigzag path, **velocity** is also used in a special sense to denote the rate of motion *in a certain direction.*

13. **Acceleration.**—When a train pulls out of a station, at first it moves slowly, but soon the speed increases. A ball dropped from a height moves faster and faster as it falls until it crashes to the ground. In both of these cases the motion has been **accelerated.** If the train at a particular instant was travelling at 10 feet per second, and later, at the end of the following seconds, its speed increased to 14, 18, 22, and 26 feet per second, we should say that its **acceleration** in each second was 4 feet *per second.* When a train **slackens** speed we use the term **retardation** for the rate by which its velocity is diminished.

14. **Motion on an Inclined Plane**—Experiment 17.—Fasten two long glass tubes side by side on

a suitable piece of wood slightly inclined, so that a steel or glass ball will just roll along without a push. Place marks along the wood at distances 1′ apart. If you possess a stop-watch, you should take the time the ball requires to travel to the 1′, 2′, and 3′ marks. Your results will not be accurate, even if your watch

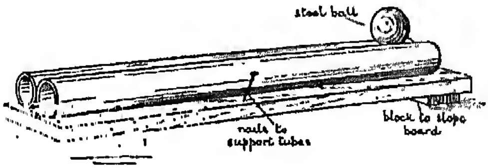


FIG. 20.

measures to the fifth of a second, but it will be quite evident that the second foot is traversed in quicker time than the first, and the third in still less time.

If you cannot obtain a stop-watch, you should vary the experiment in the following way:

Set up a simple pendulum 9¾″ long. The time of a complete oscillation of this pendulum will be almost exactly 1 second. A friend should now count out seconds aloud while watching the swing of the pendulum. Just as he calls out a second, release the ball, and place your finger at the spot you judge the ball to be at the instant he calls out the next second. The ball is placed at the starting-point again, but this time the distance travelled in *two* seconds is estimated. You will invariably find that the second result is much more than double the first, showing that the speed of the ball increases as it descends the incline.

EXPERIMENT 18.—Incline the wood to a greater angle with the table and repeat the experiment. The whole motion is more rapid; but you will prove that

in this case also the motion of the steel ball is accelerated as it travels down the incline.

EXPERIMENT 19.—Place a light string over a very easily running pulley-wheel, and attach a 1-lb. weight to each end (see Fig. 21). Now tie an ounce weight to one of the 1-lb. weights. The latter will immediately begin to descend. By watching the movement it will be seen that the motion is accelerated, or it can be tested by using the stop-watch to find the time taken to traverse 1 yd., 2 yds., and 3 yds.

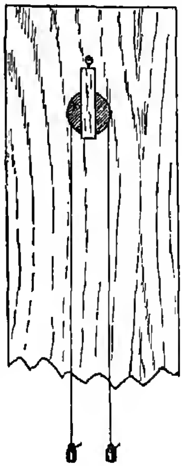


FIG. 21.

15. **Falling Bodies.**—At first it is difficult to believe that heavy bodies and light bodies will fall from the same height in the same time. Yet that is what Galileo proved when he dropped various balls from the top of the Leaning Tower at Pisa. It is worth a trial to satisfy yourself of the truth of this by dropping from a height, at the same instant first, two pieces of wood of *different* weights, and, secondly, a piece of wood and a piece of iron of the *same* weight. As far as you can judge, the wood and the iron reach the ground at exactly the same moment, and from that you would gather that they must fall *at the same rate.* But everyone knows how gently a feather will fall, usually taking quite a long time to reach the ground. Yet scientists have proved that in a space empty of air or other gases a coin and a feather will fall in *exactly the same time.* In the open, the buoyancy of the air plays a large part. For light bodies that

have *a very large surface*, the air certainly acts as a considerable check to the downward motion. We can show, however, in a simple manner that when the upward pressure of the air does not act directly on a feather or a piece of paper it descends quite quickly.

EXPERIMENT 20.—Hold the lid of a tin horizontally in one hand and a piece of paper not quite as large in the other, and drop both at the same instant. The lid falls quickly, the paper flutters about and takes longer to reach the ground. Now place the paper on the top of the lid and drop the lid as before. The piece of paper travels all the way with the lid; it does not get left behind, because now the air is not able to buoy it up as before.

It has been proved by very careful experiments that a body will fall approximately—

16 feet in	1 second,	
64 ,,	2 seconds,	
144 ,,	3 ,,	

You will notice that these numbers may be written—

(16×1)	feet in	1 second,
(16×2^2)	,,	2 seconds,
(16×3^2)	,,	3 ,,

From such results a formula has been constructed by which we can reckon the distance fallen in any given number of seconds:

$$\underset{(=\text{the distance fallen})}{S} = \underset{(t=\text{the number of seconds})}{16t^2}$$

NOTES.—(i.) *This result is only approximate, and does not take into account the resistance of the air.*

(ii.) *It also assumes that the bodies start from rest.*

16. **Horizontal Projection**—EXPERIMENT 21.—Nail a piece of wood shaped as in Fig. 22 (a) to a

board resting on a table, so that the nail forms an axis round which the wood can freely turn. Place marbles in each of the slots, and swing the wood rapidly round

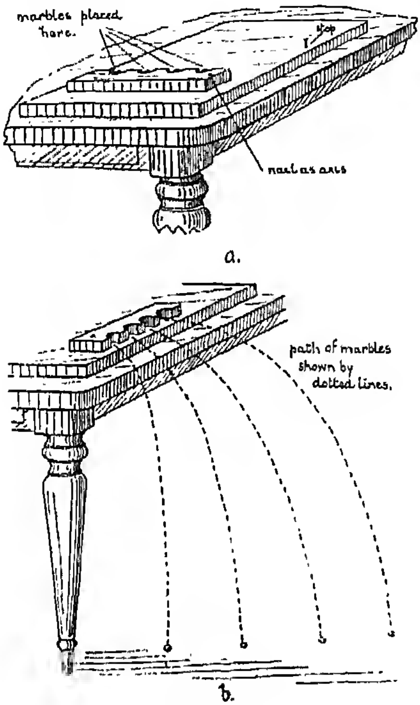


Fig. 22.

to the position shown in Fig. 22 (*b*). The marbles are propelled outwards over the edge of the table.

Note carefully—

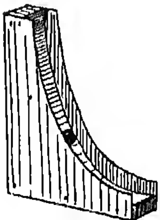
(i.) Which marble has the greatest velocity.
(ii.) ,, ,, goes farthest.
(iii.) ,, ,, touches the ground first.

Repeat the experiment several times until you are

convinced that they *all touch the ground at the same moment.* The marble nearest the axis receives hardly any forward impetus, and falls almost directly downward; the one farthest from the axis travels a long way outward, yet the *downward* time is the same.

We may gather from this that the downward pull of gravity upon a body is independent of any forward movement which the body may possess.

EXPERIMENT 22.—Construct the apparatus shown in Fig. 23 (*a*). From a piece of wood 1′ square cut


a.

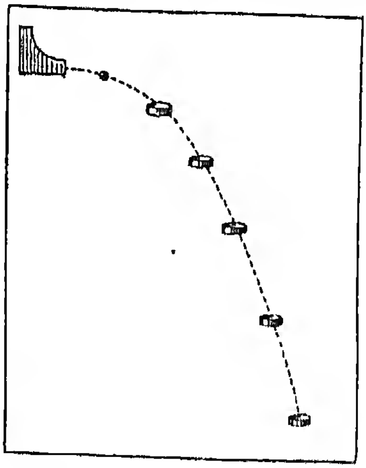

b

FIG. 23.

out a quadrant from one corner, using a radius of 10″. From two pieces of cardboard 1′ square cut out similar quadrants, but with a radius of 9½″. Brad the pieces together as indicated in the diagram, so that a large marble can roll smoothly down the groove and leave the end with a horizontal motion.

Place a blackboard by the side of the apparatus, and

hold the lid of a cocoa-tin at suitable places for the ball to jump into it, taking care that the same starting-point is used each time. Join these places, and note that the path of flight is a curve [Fig. 23 (*b*)].

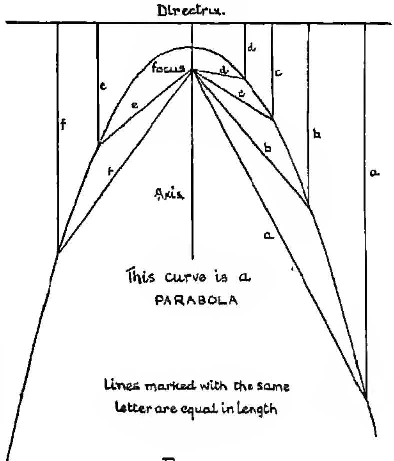


FIG. 24.

NOTE.—*The shape of the curve is always of the same kind; it is part of a curve known as a* **parabola.** *Fig.* 24 *shows a longer portion of such a curve. The special property of a parabola is that each point on the curve is at the same distance from a certain point called the* **focus** *as it is from a certain line called the* **directrix.** *In the diagram several pairs of lines have been drawn to show this, and you should measure some of these pairs and prove that they are of equal length.*

EXPERIMENT 23.—A jet of water can be used instead of the ball of Experiment 22. Fig. 25 shows how to arrange the apparatus. Dotted lines have been drawn to show that the **downward** motion (due to the effect of the pull of gravity) is very small at first, compared with the **outward** motion, but that it rapidly increases.

NOTES.—(i.) *When a ball is projected* **vertically** *into the air, the force of gravity still acts on it,* **retarding** *the motion until the ball for a moment comes to rest and then begins to fall. When it reaches the ground it will have just the same velocity as when it started on its upward path.*

If the ball is thrown upwards into the air at any other angle, the path of its flight is a parabola.

(ii.) *One of the most important applications of the above principles is the "sighting" of a rifle or cannon. If a rifle were pointed and fired directly at an object a thousand yards away, the bullet would not hit the target because gravity would have pulled it downward towards the ground. The barrel of the rifle has to be directed towards a point above the object by an amount depending on its distance This would be very difficult for anyone to judge for himself,* so on *every rifle there is a "sighting" apparatus to aid him to obtain a correct aim. On the "back-sight," which is placed near the middle of the rifle, is a* V-*shaped notch, while the "foresight" is a short ridge near the end of the barrel. Instead of looking along the length of the barrel at the object, the marksman views it so that the object and the foresight are in a straight line with the centre of the notch. The notch can be raised, and certain figures on the apparatus indicate how high the notch should be raised for various distances of the object aimed at.*

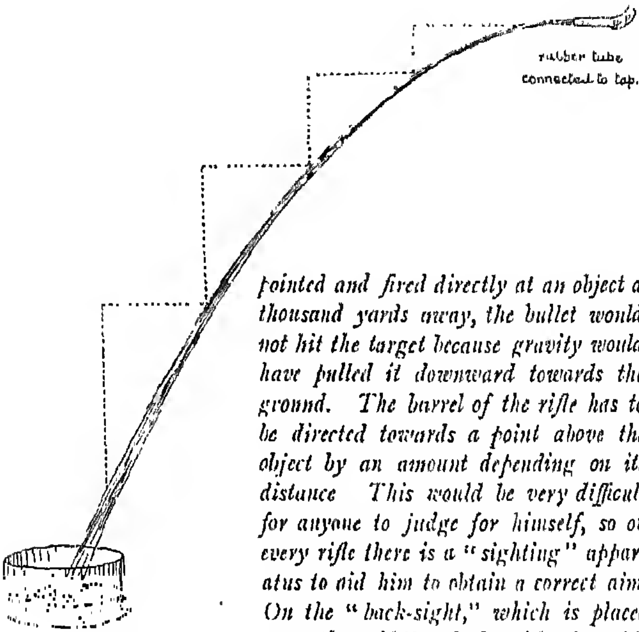


FIG. 25.

The marksman estimates the distance of the object, regulates the "sight" accordingly, aims at his object as described above, and fires. The barrel, *however, by this arrangement really points* above *the object to make allowance for the drop of the bullet in its flight.*

SUMMARY OF CHAPTER IV.

1. The **speed** of a body is its rate of motion. **Velocity** denotes *direction* as well as rate of motion.

2. When the speed of a body steadily increases, we say the motion is being **accelerated**. **Retardation** refers to the *slackening* of speed.

3. The speed of a body falling from a height or rolling down an incline is accelerated.

4. In an empty space all bodies would fall at the same rate. The distance fallen in any given time can be determined from the formula $S = 16t^2$.

5. Bodies projected horizontally from a table take the same time to reach the ground as if they were dropped from the same height.

6. The path of any body thrown into the air, other than in a vertical direction, is a parabola.

Chapter V

I. BOYLE'S LAW

17. **Pressure and Volume.**—Since all gases behave very much alike under pressure, we shall limit our experiments to air. Already we know that it possesses weight and exerts pressure. It can also be compressed, but not indefinitely. For instance, if a close-fitting piston is pushed down a strong test-tube, the air resists the movement of the piston, and although the air can be made to take up much less space, yet, as the volume *decreases*, the resistance *increases*, until we find it too strong for us to compress the air further.

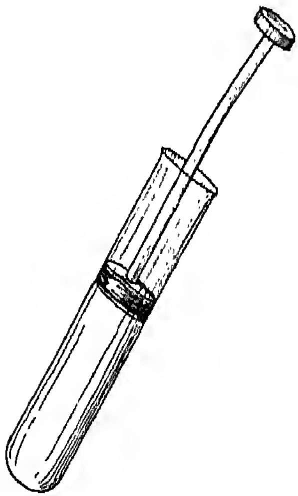


Fig. 26.

Many other examples illustrate the same principle. In a boy's toy air-gun, the piston is pushed in, confining the air inside the gun into a small space. When released, it will expel a bullet with great force, showing that the pressure of the reduced volume of air must have been considerable.

On immersing a tumbler mouth downward in a bowl of water, the water will rise a certain distance, com-

pressing the air into a smaller space. As the pressure of the air inside must be equal to the pressure of the water with which it is in contact, and as the *pressure of water increases with the depth*, it is evident that the air inside the tumbler must have increased in pressure.

Let us try to measure the compression of air and compare it with the pressure exerted.

EXPERIMENT 24.—Bend a glass tube into the shape shown in Fig. 27, and attach it to the general stand (see Book I.) by dresser-hooks, elastic bands, or by other suitable methods.

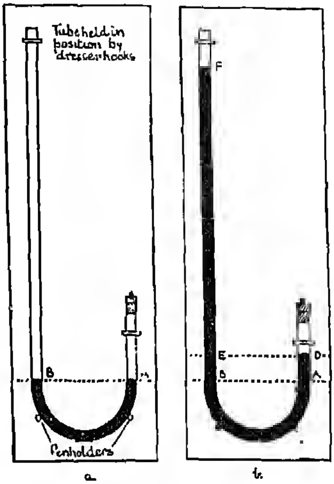


FIG. 27.

Pour mercury, by means of a small funnel, down one limb of the tube until the curved portion at the bottom is filled.

Insert a tight-fitting rubber stopper in the end of the short limb, and secure it firmly in position by a brad driven into the stand above it.

Arrange a yard measure so that the heights of the mercury can be read.

Note that the mercury in each limb stands at the same height; this indicates that the pressure of the enclosed air is equal to that of the outside air.

Pour some more mercury into the long tube. The mercury rises in *both* limbs but much more in the longer one, because the enclosed air resists being compressed into a smaller space.

Fig. 27 (*b*) represents what happens in such a case. In one tube, the mercury has risen from *A* to *D*, in the other from *B* to *F*. Since the volume of the enclosed air has diminished, its pressure must have increased. *What is the value of this new pressure?*

Draw the *horizontal* line *DE*. Measure *EF*. The pressure above the surface at $E =$ the pressure of the air above $F +$ the pressure due to the weight of the mercury column from *E* to *F*.

But since the mercury in the bend of the tube is at rest, the downward pressure on the mercury at *D* must be equal to the downward pressure on the mercury at *E* (in the same horizontal line).

NOTE.—*Since the bore of the tube is the same throughout, you will see that a column of air inside the tube 2″ long has twice the* volume *of a column of air 1″ long. Consequently we can compare volumes inside the tube by simply comparing lengths or heights.*

We can ascertain the air pressure at the open end *F* by reading a barometer. Suppose, for example, it stands at 30 inches, and that *EF* is 10″ long. Then the pressure at $E = 40$ inches of mercury, and the pressure of the confined air is also equal to a pressure of 40 inches of mercury, or about $1\frac{1}{3}$ atmospheres.

EXPERIMENT 25.—Again prepare the apparatus with the mercury standing at equal heights in each arm, as at the beginning of the last experiment.

Carefully note the length of the column of enclosed air to the nearest tenth of an inch.

Add mercury as before, but only about one or two inches at a time, and after each addition carefully note—

(*a*) The length of the enclosed air column.

(*b*) The *difference* between the heights of the mercury columns.

Remember that the *pressure* of the enclosed air is

found by adding the *height* of the barometer (giving the pressure of the air outside) to this *difference* in heights.

Make a table of your results as follows:

1. Column of Enclosed Air.	2. Total Pressure of Enclosed Air. (Height of Barometer + Difference of Levels.)	3. Volume × Pressure.

You already know that as the total pressure *increases*, the column of enclosed air *decreases*, but you will see that there is a close connection between the two shown in column 3.

The product of the volume and pressure remains the same.

This is known as **Boyle's law**. If the pressure on a gas is increased to a pressure 7 times as great, then its volume will be diminished to $\frac{1}{7}$ of its former volume.

NOTE.—*The law is true for all ordinary cases, but when very great pressures are used there is usually a slight departure from it.*

II. DIFFUSION OF GASES

18. **Collecting Gases.**—Hydrogen, being a very *light* gas, can be collected by **upward displacement**, carbon dioxide by **downward displacement** because it is *heavier* than air.

Yet if a jar of carbon dioxide is left open *with mouth upward* and tested at intervals, in time it will be found

that very little carbon dioxide is left; it has diffused into the air and air has taken its place in the jar.

A similar experiment can be carried out with hydrogen. Allow a jar to rest mouth downward on two blocks, as shown in Fig. 28. After half-an-hour it will be difficult to trace any hydrogen left in the jar.

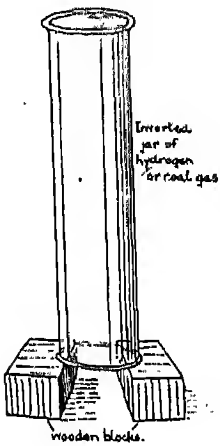


FIG. 28.

All gases, placed together, tend to mix until the mixture is uniform throughout. For instance, if a gas jar full of a very light gas like hydrogen is inverted over a similar jar full of a heavy gas like carbon dioxide and left, the continuous motion of the tiny particles of the gases will cause them to intermingle until there are equal amounts of each gas in both jars.

This process is known as **diffusion.**

19. **Rate of Diffusion.**—It was discovered by the scientist Graham, that if two gases, one heavier than the other, were separated from each other by a porous partition, the gases would pass through the walls and mix. He also found that the lighter gas passed through **more quickly.**

EXPERIMENT 26.—Obtain a porous pot such as is used in many electrical cells and fit the open end with a stout cork. Through the cork bore two holes, pass a long glass tube through one, and fit the other with a plug.

NOTE.—*The cork should be covered with melted paraffin wax to make it airtight*

Keeping the plug-hole *open*, fill the pot with coal-gas. (Connect the long tube by rubber tubing to the gas-jet.) When filled, *insert the plug* and place the tube in water, as shown (Fig. 29).

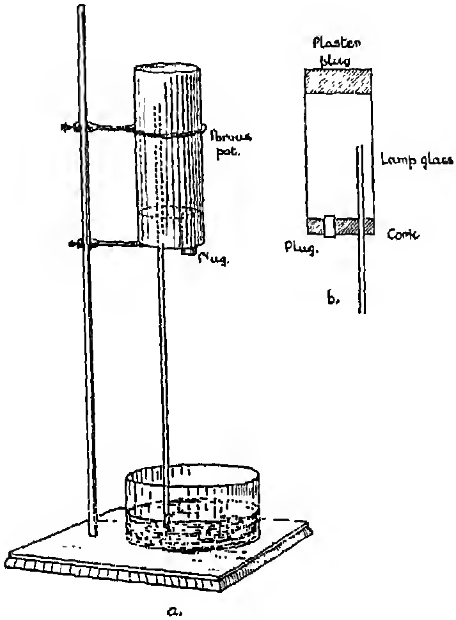


Fig. 29.

The coal-gas diffuses through the porous pot *more rapidly* than the air can make its way in; consequently the water ascends in the tube.

Note.—*If a porous pot is not available, a lamp-glass or wide glass tube can be plugged at one end with a paste of plaster of Paris and left until it is quite set.*

Experiment 27.—The previous experiment can be reversed by holding an inverted jar of coal-gas over the top of a diffusion-tube filled with air.

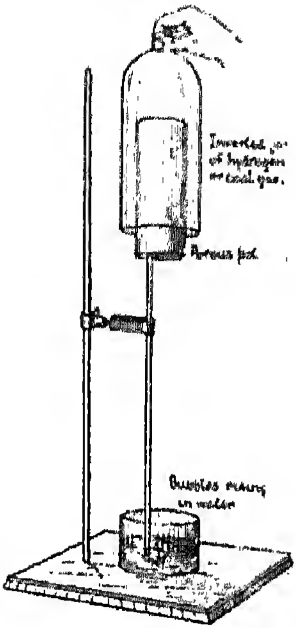


FIG. 30.

The coal-gas outside diffuses into the tube more quickly than the air inside diffuses out. This increases the pressure inside the tube and some of the air (or, rather, mixture of air and coal-gas) is forced down until it finds an escape at the bottom of the tube (Fig. 30).

This can be seen by the bubbles rising in the water.

SUMMARY OF CHAPTER V.

Boyle's Law.

1. A gas can be compressed, but its resistance (*i.e.*, its pressure) increases as its volume decreases.

2. By experimenting with various pressures on an enclosed volume of gas (usually air) it has been found that, with the same mass of gas—

The product of the volume and pressure is constant.

This is known as Boyle's Law.

Diffusion of Gases.

1. All gases placed together tend to mix until the mixture is uniform throughout.

2. When two gases of unequal densities are separated by a porous partition they diffuse through the walls, but the lighter gas passes through at a more rapid rate than the other.

SECTION II.—SOUND

CHAPTER VI

ORIGIN AND TRANSMISSION OF SOUND

20. **Origin of Sound.**—From their infancy children delight in sounds. Asked for the cause of sound, they would probably point to the bugle, drum, or other instrument which they could see someone blowing or beating near at hand. *But why should the blowing of a bugle give out a note, and how is it that we are able to hear it?*

EXPERIMENT 28.—(*a*) Sound a tuning-fork by striking a prong against the table. Look at the prongs. You note that their outline is blurred; the prongs are evidently moving rapidly to and fro—that is, they are in a state of vibration; a musical note can be heard also.

(*b*) Touch your teeth with the sounding fork, and notice the jarring effect caused by the rapid vibrations.

(*c*) Touch one of the prongs lightly on the surface of water contained in a bowl and observe the ripples produced.

(*d*) Fix the tuning-fork in a hole in a cigar-box. Make a knot at the end of a thin piece of string. Sound the tuning-fork, either by pinching the prongs together and releasing them, or by drawing a violin bow across the prongs. Hold the string so that the

knot just touches the sounding fork—the knot will be knocked aside (Fig. 31).

(*e*) To the end of one of the prongs attach a fine broom-bristle by means of gummed paper or sealing-wax.

Blacken one side of a stout piece of cardboard by holding it over a candle-flame. Sound the fork and lightly draw the vibrating bristle along the card. After

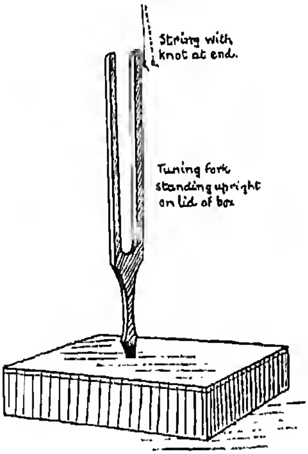


FIG. 31.

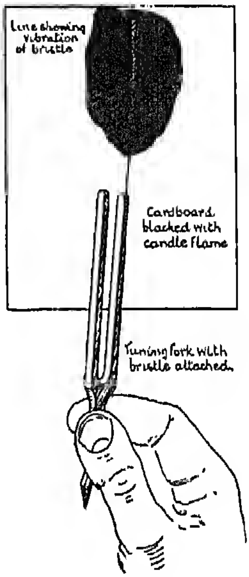


FIG. 32.

practising the movement several times, you will find that it is possible to do it so that a trace of the vibrations of the bristle is left on the blackened surface (Fig. 32).

(*f*) The last experiment can be varied by blackening one side of a pane of glass and letting it slide down the face of an almost upright drawing-board, at the same

time touching the surface with the vibrating bristle (Fig. 33).

Experiment 29.—Stretch a string tightly between two pegs. Pluck it. A musical note is given out, and on observing the string we notice that it is rapidly vibrating. In this case also we find that there is a connection between a musical sound and vibration.

Experiment 30.—(*a*) Clamp one end of a long steel or iron rod, and set the free end in vibration. A deep note is heard. If the vibrations were recorded by means of a bristle and the apparatus used in Experiment 28, it would be found that they were slower—that is, there would be fewer waves on the card if it moved downward at the same rate as before.

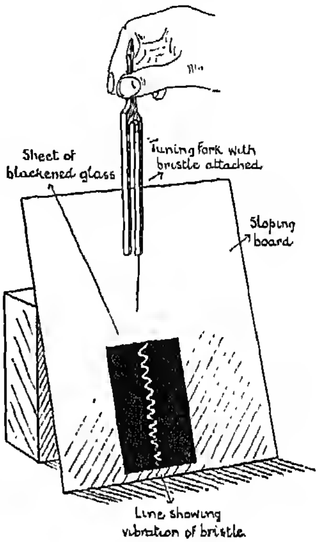


Fig. 33.

(*b*) Strike a bell and touch the rim. The vibrations can be felt.

Whenever a musical sound is emitted, we shall find, on looking for the cause, that something is in a state of vibration.

21. **How we Hear.**—The vibration of a tuning-fork is the *cause* of the note it gives, *but what conveys the note to the ear?* In most cases it is the air. This does not mean, however, that when we hear the sound

of a bell, the air travels from us to the bell after each stroke. It has been discovered that sound is transmitted in the form of waves.

To understand that waves can be transmitted without the particles of the medium moving very far, try the following simple experiments.

EXPERIMENT 31.—Lay two pieces of glass tubing side by side, with suitable blocks to keep them together. In the groove, place some marbles (*e.g.*, six).

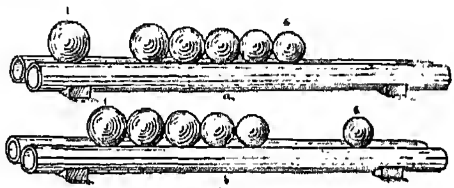


FIG. 34.

Draw back number one (Fig. 34 (*a*), and then give it a quick motion towards the second, which will *receive* the impact, but will remain almost exactly in the same place. The blow, however, will be passed on from one marble to the next until it reaches the last. Having nothing to prevent its motion, it flies off from the rest as shown in Fig. 34 (*b*).

EXPERIMENT 32.—Float on a large bowl of water some pieces of cork or paper. Dip your finger with a sharp movement into the centre of the bowl. Waves start from this spot and quickly reach the margin; the pieces of cork or paper rise and fall, but are not carried to the edge by the wave. (Compare this with the motion of a boat on the sea.)

EXPERIMENT 33.—Place a lighted candle in front of a wide glass tube as shown. Burn a piece of paper and allow the smoke to enter the tube. Clap two

books violently together. An air wave will travel through the pipe and blow aside the candle-flame, but the smoke will scarcely move. (A screen of card-board should be arranged to prevent the air impulses from the books acting on the flame except through the tube.)

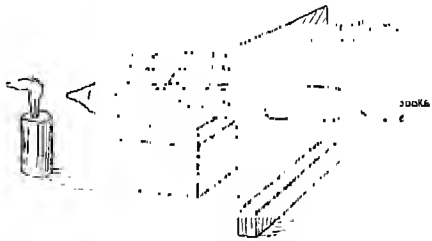


FIG. 35.

Suppose that a steel rod is placed in a vice, as in Fig. 36, and the end attached to a very long and light spiral spring, the other end of which is fixed. If this rod be made to vibrate to and fro, the spirals *nearest the rod* will be alternately compressed and separated. The compressions and separations will pass to the neighbouring spirals, and so on through the spring right to the end. After a short time the spring will be in the state represented in the figure, the spirals of the wire being

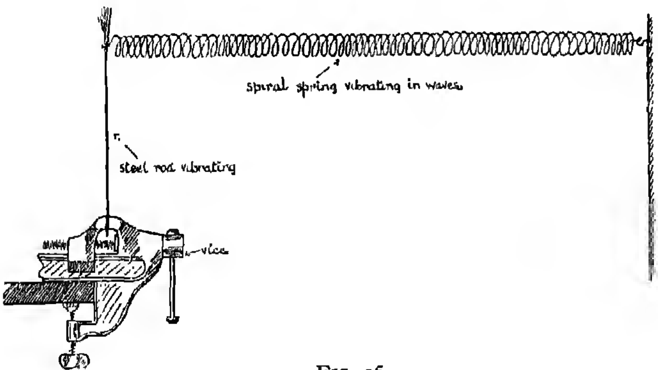


FIG. 36.

divided into sections *alternately compressed and drawn out,* and these pulses or waves of motion will travel continuously from the rod to the fixed end as long as the rod continues to vibrate.

Suppose a tuning-fork is sounded and then held at the end of an open tube, as in Fig. 37. Consider the motion of the nearest prong. When it moves *towards*

FIG. 37.

the tube, the air at the entrance becomes condensed or compressed. But it does not remain so. In its effort to expand again to its original volume, *it compresses the next layer,* which in turn affects the next layer, and so the compression passes along the tube. When the prong moves *away* from the tube, it gives more space than usual to the air at the entrance of the tube, and so a rarefaction (or expansion) is produced at that place. This in turn draws air from the next layer to it, and so on. Thus, as the vibration of the prong continues, a series of condensations and rarefactions pass down the tube.

NOTES.—(i.) *In the diagram you are shown the state of the air inside the tube* at a particular moment. *Of course, air is invisible, but the crowded lines show the spots where the air is compressed. Those are the* condensations. *Midway between them the air seems less packed; these are the* rarefactions. *But you will remember how the waves of the sea travel onward, that where there is a* ridge, *immediately afterwards there is a* trough,

so in the tube, the crowded lines seem to move along to the left, followed by those more drawn-out.

(ii.) *The distance between the centre of a condensation and the centre of the next condensation is called the* **wave-length**.

(iii.) *The particles of the air do not travel along the tube, they merely swing to and fro.*

22. **Passage of Sound through various Bodies.**—Air is not the only substance which will transmit sound.

EXPERIMENT 34.—(*a*) Place a watch at one end of a long table, and listen to the ticking when the ear is pressed close against the other end. The sound is not only more powerful, but deeper in tone than that which comes to us through the air. In this case the wood conveys the sound.

(*b*) Get a comrade to sound a tuning-fork and place the stem on an iron water-pipe, and note the effect at various distances from the fork, both when the ear is pressed close to the pipe and when raised from it.

(*c*) Place a watch inside a glass jar and close the mouth with a cork. The watch can still be heard, although the air does not communicate with that outside. The sound passes through the glass walls.

NOTE.—*Indian trackers place their ears close to the ground when they wish to detect the approach of anyone from a distance.*

Sound requires a Medium—EXPERIMENT 35.—Fit a flask with a stopper, through which a piece of stout wire and a short length of glass tubing has been passed. Attach some rubber tubing to the glass tubing, and obtain a clip for it. Fasten a small bell to the wire, as shown in Fig. 38. Put some water in the flask.

(*a*) Shake the flask and note the intensity of the sound, both with the clip on and off.

(*b*) Remove the clip and boil the water over a Bunsen burner until all the air is expelled. Remove the flame and clip the tubing. When the flask is cool,

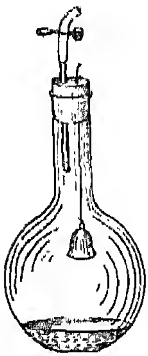


FIG. 38.

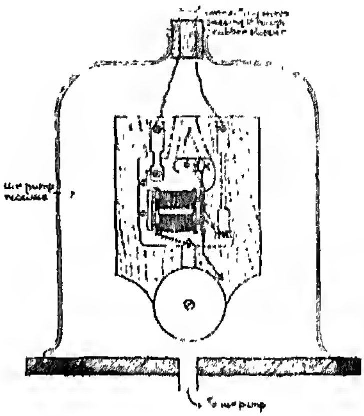


FIG. 39.

shake it again. The sound can scarcely be heard. You will note that since the *air* has been expelled and most of the *vapour* has cooled and condensed, there is almost a vacuum around the bell.

EXPERIMENT 36.—If an air-pump and receiver can be obtained, a much more satisfactory experiment can be carried out by suspending an electric bell inside the receiver, as shown in Fig. 39, the connecting wires being carried through the rubber stopper. (*See that the stopper is then thoroughly airtight.*) Ring the bell by connecting the wires to the poles of a battery. Note the intensity of the sound. Pump out the air, and at intervals ring the bell and so judge the effect of the decreasing air-pressure on the intensity of the sound.

When the air has been almost exhausted, the sound of the bell is very faint indeed.

Sound will **not travel in a vacuum.** Unlike light and heat, it cannot be transmitted by the ether of space.

23. **Velocity of Sound.**—Most boys know that it takes time for sound to travel. Probably they have watched a workman on a distant roof strike a blow with a hammer and heard the *sound* of the blow *when the hammer has been raised again to strike.* Or they may have observed the jet of steam from the whistle of a locomotive a long way off and the sound of the whistle has reached their ears *one or two seconds later.*

We see a lightning flash, but the thunder, *produced at the same moment,* may not arrive for many seconds. Scientists have found that **sound travels about 1,100 feet per second in still air,** but many times faster in wood and iron. Even in water, sound travels four times as quickly as in air.

You will notice that 1,100 feet is just over one-fifth of a mile. You can, therefore, gauge the distance of a thunderstorm in the following way. Light travels at the enormous rate of 180,000 miles per second, so that a flash of lightning becomes visible to us almost instantaneously, even when it takes place many miles away. We can assume, therefore, that the time which elapses between seeing the lightning flash and hearing the thunder is simply the time which the sound of the thunder takes to travel to us. By counting the number of seconds between the flash and the report and dividing the number by 5, we shall know approximately the distance of the storm in miles.

NOTE.—*The principle of estimating distances by the time sound takes to travel from one place to another was used very successfully*

during the Great War to locate the positions of hostile batteries accurately. A body of men called Sound-Rangers were engaged on this special work and proved to be of great service. A more detailed account of the method is given in the Appendix.

24. **Intensity of Sound.**—When a bell is struck the sound travels in every direction, providing there are no obstacles in its path. Each condensation or rarefaction will, therefore, have the shape of a hollow ball, and you must imagine the ball growing larger and larger, travelling farther and farther away from the bell.

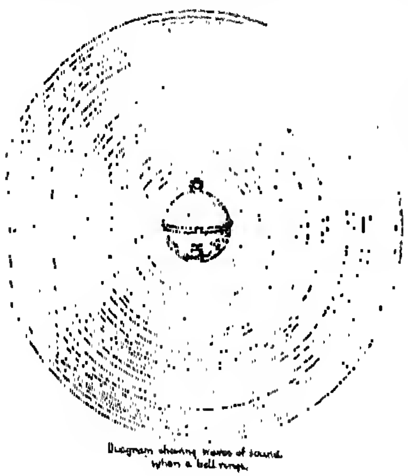


FIG. 40.

Also, the vibrating bell contains *energy* which it distributes to the air particles around it. According to the amount of energy which is thus communicated, so the sound is loud or soft. The energy, which at first is given to a small group of air particles immediately surrounding the bell, is by them distributed outwards to the particles of the sphere surrounding the first one. Consequently the energy becomes distributed over a bigger and bigger area as the sound travels away from the bell. Since a sphere with *twice* the *radius* of another has a *surface* four times as great, it is clear that when we are at *twice* the distance from a particular sound, it will only seem *one-quarter* as loud.

The loudness of sound varies in proportion to the square of the distance from the source of the sound.

It has been mentioned that the loudness or softness of a sound as heard at one particular place depends on the amount of energy given out by the sounding instrument. Since this energy is obtained from the vibration of the particles of the sounding instrument, you will understand that the greater the amplitude of the vibrations the louder will be the sound. To produce as loud a sound as possible with a tuning-fork we strike it *smartly* against a hard object; to obtain a loud note with a string we pluck it *forcibly*—thus causing the particles of the fork or string to vibrate through a *wider* distance. This increases the energy of motion, some of which is communicated by impact to the air around.

From your study of the pendulum you have already learnt that however big the swing of the pendulum *the time taken for each swing remains almost exactly the same.* Similarly, however hard we strike the tuning-fork, *the number of vibrations per second will remain the same and the same note will be heard.*

Loudness again is affected by *the area of the vibrating body*. Strike a tuning-fork and hold it in the air; the sound is hardly heard. Put the stem of the vibrating fork against a table or box; the sound is much louder. The vibrations of the tuning-fork have caused the wood to vibrate also, and thus a greater volume of air is set in motion.

Many musical instruments have such a "sound-box." When the strings of a violin are set in vibration by the drawing of the bow across them, the vibrations are communicated by means of the bridge to the body of the instrument, and it is mainly the latter which sets the air in vibration and enables the music produced to be heard at a distance.

25. **Reflection of Sound.**—We know that voices do not sound quite the same in the open air as they do in a room. In the former case the sound waves travel without interruption from the speaker to the listener, but in a room the walls play an important part.

EXPERIMENT 37.—Suspend a watch in front of a screen and move to a position behind the screen at which

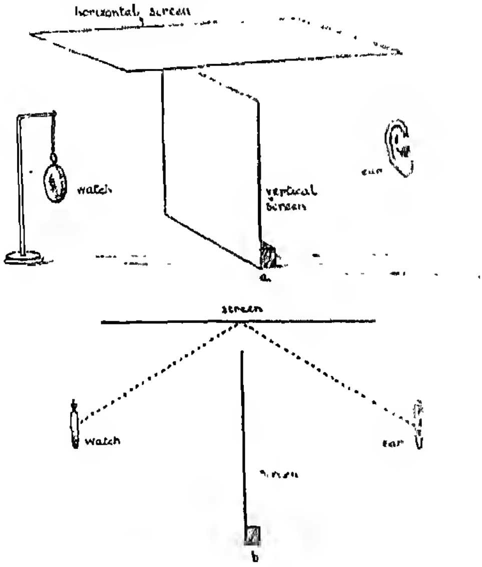


FIG. 41.

the watch becomes just inaudible. Now hold a large piece of cardboard over the screen [Fig. 41 (*a*)]. The ticking will probably be heard quite plainly. The sound waves have been **reflected** from the cardboard, just as we found light was reflected from a mirror [see Fig. 41 (*b*) for diagram]. Thus the sound of a person's voice in a room comes to us not only *directly* through the air, but also as a *reflection* from many surfaces.

Echoes are due to the reflection of sound waves. If you stand about a hundred feet or more from a high cliff or wall and give a loud exclamation or whistle you will hear it repeated as an echo. The sound wave has travelled to the cliff and been reflected. The greater the distance the longer the time before the echo is heard. At a short distance the echo mingles with the sound given out and thus is not heard.

Sometimes, as in a valley, the sound waves rebound from one side to another and give rise to **repeated echoes.**

SUMMARY OF CHAPTER VI.

Sound.

1. On tracing the cause of sound, we shall find something in a state of **vibration.**

2. Sound is transmitted to us in the form of waves which require a medium in which to travel—that is, sound will not travel in a vacuum.

3. Sound is mostly conveyed to us by the air, but it can be carried quite easily and faster by water, wood, and metals.

4. The speed of sound in air is about 1,100 feet per second.

5. Sound waves are a series of **condensations** (or compressions) and **rarefactions** (or separations). These waves are hollow spheres in shape, which increase in size as they travel outward.

6. The **wave-length** in air is the distance between one condensation and the next.

7. Sound varies in intensity in proportion to the **square** of the distance.

8. A "sound-box" is used to intensify the sound produced, by throwing a greater area into vibration.

9. Echoes are due to the **reflection** of sound.

CHAPTER VII

MUSICAL SOUNDS

26. **Pitch.**—When a musical note is higher than another we say that its pitch is higher. A man's voice is usually *lower* in pitch than a boy's. **Pitch depends on the frequency of vibration**—that is, the **number of vibrations per second.** You know that most electric motors vibrate somewhat when working, giving out a musical hum, which rises in pitch when the armature increases its speed, and falls in pitch when the speed slackens.

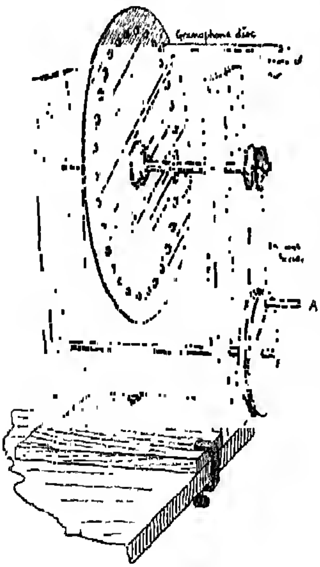


FIG. 42.

We can also prove that pitch depends on frequency by using two forks of different pitch with the apparatus of Experiment 28. The fork giving the higher note will also give the greater number of waved lines while the smoked glass falls.

The air can be thrown into vibration in another way, besides those already mentioned. Look at the apparatus represented in Fig. 42. It consists of a disc, with a circular row of holes, close together, but

at *perfectly equidistant intervals.* The disc is mounted on an axle, and so arranged that it can be rapidly driven by turning the handle at *A*.

While the disc is made to revolve, air is blown through a rubber or glass tube, with one end held near the holes, as shown. As each hole passes the end of the tube, a puff of air blows through it, and since the holes are equally spaced, **these puffs follow each other at a regular rate.** From the disc, therefore, a series of **condensations** (*i.e.*, the puffs) will set forth from near the end of the tube, and give rise to a musical note.

This note will be low in pitch if the rotation of the disc is slow, but will **rise in pitch with increase of speed.**

NOTES.—(i.) *A disused gramophone disc is very useful for this purpose, although, as it is brittle, care must be exercised in setting it up.*

(ii.) *If another row of holes at* **unequal intervals** *is bored, the result, when the stream of air strikes the moving disc, is unpleasant. The difference between a* **musical note** *and a* **noise** *is that in the former the* **vibrations** *take place at* **regular intervals,** *while in the latter the* **vibrations** *are* **irregular.**

(iii.) *Either a large number of holes or a large number of revolutions per second would be required to produce a note such as a boy could sing. A row of* 60 *holes and* 9 *revolutions per second would produce a note slightly higher than that of the usual school tuning-fork.*

27. The Musical Scale.—Most of you have learnt to sing such a scale as is shown in Fig. 43, either by the Staff notation or by Tonic Sol-fa notes.

C D E F G A B C

doh ray me fah soh lah te doh

1 9/8 5/4 4/3 3/2 5/3 15/8 2

FIG. 43.

The first note, *C*, has no less than 256 vibra-

tions per second, while the last note, *C*, which is very *similar* in sound, but *higher* in pitch, has a frequency of 512 vibrations per second—that is, exactly twice as many.

From the fractions given below the notes, the frequency of any one of them can be found—thus, *G* is represented by $\frac{3}{2}$, and therefore its number of vibrations per second is $\frac{3}{2} \times 256 = 384$.

28. **Length of Waves.**—It is very important that you should realize that whatever may be the *pitch* of a note—that is, whatever the *rate of vibration* or *frequency*—the sound of it travels away from the source at the *same rate*. If two boys walk at exactly the same rate, but one takes much quicker steps than the other, it is evident that the length of his step is shorter than that of the other boy. Similarly, in sound, a high-pitch note has a greater frequency but a smaller wave-length than a low-pitch note.

If we know the frequency of a note, we can easily calculate the length of the wave. (Refer to Fig. 37. In this case the wave-length is the distance between one *condensation and the next.*)

Suppose the frequency is 256 per second (the sound of *C*), then, since sound travels 1,100 ft. per second, by the time the first condensation has travelled 1,100 ft. outwards, 255 other condensations will have followed it at regular intervals. Thus in a distance of 1,100 ft. there will be 256 points of condensation. Therefore the wave-length in this case is 1,100 ft. $\div$ 256 = 4·2 ft.

SUMMARY OF CHAPTER VII.

Musical Sounds.

1. Musical sounds vary in pitch. Some are *low*, others are *high* in pitch. Pitch depends on the number of vibrations per second of the sounding body. An increase in the frequency of vibration causes a rise in pitch.

2. Musical sounds are caused by regular vibrations. Irregular vibrations give rise to noise.

3. The musical scale has been founded upon the difference of pitch of notes. The numbers representing the frequencies of the notes of the common scale are simple fractions of one another.

4. From the knowledge of the speed of sound in air and the *frequency* of a tuning-fork we can calculate the length of the sound-wave in air of the particular note the tuning-fork gives.

CHAPTER VIII

VIBRATION OF STRINGS

29. **A Sounding-Box.**—For studying the sounds made by strings, we need a sounding-box. In the form shown in Fig. 44 a steel or copper wire is fastened to a dresser-hook at one end, passes over two triangular bridges (A and B), and a pulley-wheel (P), and is kept taut by the weight (W).

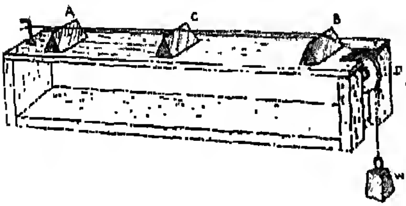


FIG. 44.

NOTE.—*A box with a length of 3′ and a cross section 4″ × 3″ will be found to be very suitable. The wood of the top of the sounding-box should be thin and strong, preferably of pitch-pine.*

EXPERIMENT 38.—By using different weights at W, prove by plucking the wire between A and B that the greater the tension (*i.e.*, the force which stretches the wire) the higher the note produced.

EXPERIMENT 39.—(*a*) Place a third bridge (C) between A and B, and again pluck the wire. Prove that *with the same stretching force* the shorter the length, the higher the note produced.

(*b*) Place the bridge (C) in the middle and prove that the note produced from each half is the octave of the note produced by the whole string.

(*c*) Place the bridge at $\frac{1}{6}$, $\frac{1}{5}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$ of the whole length from A in succession, and test the notes given out by the portion CB.

NOTES.—(i.) *A sounding-box used in this manner is often called a* **sonometer** *or* **monochord.**

(ii.) *A table-drawer makes an excellent sonometer, which can be set up in a very short time* (Fig. 45).

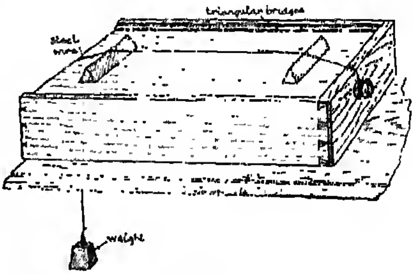


FIG. 45.

(iii.) *With a slight alteration of detail, the sonometer shown in* Fig. 44 *could be arranged for two or more strings to be mounted side by side. By suitably placing the movable bridges, the strings could be tuned to give different notes and a musical chord produced.*

(iv.) *A violin is "tuned" by increasing the tension on the strings. A higher note is obtained during the playing of the instrument by moving the finger up the string, thus shortening the vibration length.*

EXPERIMENT 40.—Place several "riders" on the wire of the monochord (*i.e.*, strips of paper folded as shown in Fig. 46 (*a*), and pluck the wire at any place

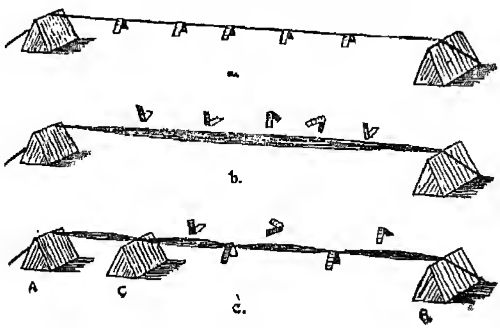


FIG. 46.

along its length. All the riders are thrown off, showing that the *whole* of the wire is vibrating. Fig. 46 (*b*) shows the appearance of the wire in vibration.

EXPERIMENT 41.—Arrange *C*, the movable bridge, so than AC is $\frac{1}{4}$ AB. Place several riders along CB, but pluck the portion between A and C. Most of the riders will be thrown off, but after several trials *you will find two points where the riders are not affected.* In this case, Fig. 46 (*c*) gives the appearance of the wire in vibration. The two stationary points are called nodes.

Try to find the nodes when AC is $\frac{1}{5}$, $\frac{1}{6}$, $\frac{1}{8}$ of AB.

NOTE.—*Instead of using the movable bridge, the string can be "damped" by placing the finger at various points along the string and pressing lightly.*

EXPERIMENT 42.—Set up the sonometer with two strings, and arrange that they give exactly the same note when plucked. (Experiments 38 and 39 will tell you how this can be done.) Place several small paper riders on one string and pluck the other. *The riders fall off,* showing that the vibration of one string has caused the other to vibrate also.

Test whether this happens when the strings are tuned to different pitches.

SUMMARY OF CHAPTER VIII.

Vibration of Strings.

1. The greater the force stretching the string, the higher the note it will give.

2. The shorter the length of string, the higher the note produced by it.

3. If a vibrating string is pressed at certain points along its length, the string can be made to vibrate in sections. The stationary points between the sections are called **nodes.**

4. A string tuned to the same note as another and placed near it will vibrate in sympathy if the second string is plucked.

Chapter IX

RESONANCE

30. **Augmenting the Sound**—Experiment 43.—Take a tall jar and sound a tuning-fork over it. Note whether the sound of the fork is increased. Pour water, a little at a time, into the jar, and keep sounding the fork over it. At a certain height of water—that is, when the air column in the jar is of a certain length—the sound will be much louder [Fig. 47 (*a*)].

Try a fork of a different pitch. A different length of air column is necessary to obtain the greatest effect: longer for a lower note, shorter for a higher note.

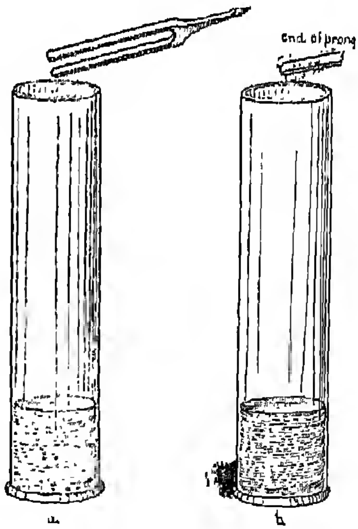


Fig. 47.

Note.—Fig. 47 (*b*) *shows one prong of the fork as it vibrates. When it swings downward, it causes a wave of air compression to travel down the tube. When it swings upward*, if the wave of compression has just had time to reach the bottom and return, *this upward swing will be strengthened and a louder note will be the result.* (*We found the correct length of air column for this to occur by adjusting the height of the water.*)

It is clear that the air wave travelled twice the length of the air column in the jar, while the fork made half a vibration. The air wave, therefore, travels four times the length of the air column while the fork vibrates once.

NOTE.—*This fact can be tested by calculating the wave-length by means of the information given in paragraph* 28 (*p.* 56).

Such a jar which augments sound is called a **resonator.**

EXPERIMENT 44.—Blow gently across the mouth of the jar. You will hear a note of the same pitch as that of the fork, showing that a given length of vibrating air column not only strengthens a note of a certain pitch, but also gives out the same note.

Organ-pipes and many other musical instruments, such as the cornet, flute, and tin-whistle, depend on vibrating air columns for their sounds. The length of the air column in most of them can be regulated by pressing keys arranged along their length.

31. **Organ Pipes.**—These are either stopped at one end or open at both ends. One effect of this can be studied by blowing across the end of a piece of wide glass tubing, first with both the ends open, and secondly with one end stopped by a finger. The note from an open pipe is an octave higher than that from a stopped pipe of the same length.

In the organ the range of notes is obtained by using pipes of different lengths.

32. **The Gramophone.**—*In what way does a gramophone record and reproduce sounds?* The parts of a gramophone are too familiar to need much description. To obtain a record, in the first place, the recording disc is given a coating of soft wax or similar substance.

Against this presses lightly the needle which is attached to the back of a small drum—a tightly-stretched membrane—against which the sound waves strike when they travel down the horn. All the changes in the sound waves affect the movements of the membrane, and consequently those of the needle. The vibrations of the needle are "written down" by the different indentations and scratchings which the point makes on the soft surface.

If the disc remained still, these markings would be over one another and therefore useless, but it is kept in motion by a clockwork, and so arranged that the needle seems to describe a spiral curve on the disc. On examination of this curve with the aid of a magnifying glass it will be seen to consist of tiny vibration-curves somewhat similar to those made by the tuning-fork.

From this first disc a metal mould is made, by means of which other discs are moulded in harder material, and these are the discs sold in the shops. If one of the latter is set in motion on a gramophone, and the needle placed at the "starting-point," the latter will follow accurately the little markings, and thus make exactly the same movements as the recording needle made. These movements will cause the membrane to vibrate and throw the air in the horn into vibrations similar to those made by the original sound waves in the recording instrument. Thus we are able to reproduce as many times as we wish the music, speech, or other sounds received by the horn of a recording instrument.

SUMMARY OF CHAPTER IX.

1. The note of a vibrating fork or string may be augmented by the use of a suitable resonator. In the latter a column of air vibrates, whose length is one-quarter of the wave-length of the note being sounded.

2. The flute and kindred instruments depend for their notes on vibrating air columns. To alter the pitch of the note, the length of the air column is altered by pressing certain keys along the instrument.

3. Organ pipes may be open at both ends, or stopped at one end. The note from an open pipe is an octave higher than from a stopped pipe of equal length.

SECTION III.—LIGHT

CHAPTER X

SPHERICAL MIRRORS

33. **Reflection from Curved Surfaces.**—Many lamps have **reflectors** behind them to throw a beam of light most strongly in one direction. As a rule, these have the form of part of a globe or sphere, and are therefore called **spherical mirrors.** Fig. 48 shows a section of one. (As the surface is spherical, the section will be circular.) If the *inner* surface is polished, it is a **concave mirror**; if the *outer*, it is a **convex** mirror.

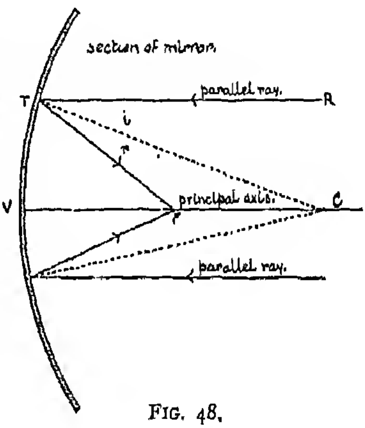


FIG. 48.

Take the case of the *concave* mirror. The centre of the sphere of which the mirror is a part is called the **centre of curvature**, and the line passing through this point to the vertex (the central point of the mirror itself) is called the **principal axis.**

You already know that a perpendicular line to the surface of *any* mirror is called a **normal.** *How would you draw a normal from a point on the arc of a circle?* In this case, we draw it perpendicular to the *tangent* at

that point, and we find that the normal passes through the centre of the circle. This is true not only of a circle but of a sphere. All normals to the surface of a spherical mirror pass through the centre of curvature.

Now, suppose that rays of light fall upon the mirror, *in what direction will they be reflected?* You will remember that for *flat* mirrors we found that the incident ray and its reflected ray made *equal* angles with the normal. This is also true of curved surfaces.

Let us discuss a simple case. In Fig. 48 two rays (each parallel to the principal axis) are shown falling on the mirror. To find the path of reflection for the ray RT, join T to the centre of curvature C. Measure the angle i and make the angle r on the other side of TC equal to i. Then TF is the path of the reflected ray. On constructing the path of reflection for the ray SP we find it also passes through F (or extremely near it).

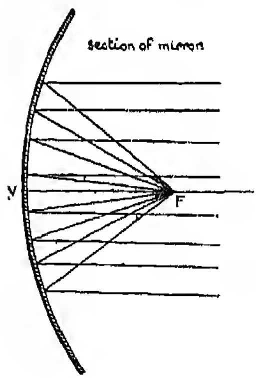


FIG. 49.

If there were a hundred such parallel rays falling on the mirror *close to* V, their reflected rays would all pass through F (or extremely close to it). (See Fig. 49.)

The point F is called the principal focus of the mirror, and is situated midway between C and V.

But you will naturally ask how parallel rays are obtained. On considering it for a moment, you will see that all rays falling on the mirror from a distant source of light must be almost parallel, especially if we choose such a distant source as the sun.

34. **Images in Concave Mirrors.**—Of course, *all* rays do not come from a great distance, and we must find the path of reflected rays when light falls on the mirror from objects only a few feet away.

Fig. 50 represents a candle placed in front of a concave mirror. Rays will proceed from the candle in *all* directions. In (*a*) we have traced the course of two of them from the tip of the candle-flame. The ray *AS* passes through *C* (the centre of curvature), and must therefore be reflected back along the same line. (A moment's thought will show you the reason for this.) The ray *AT* is parallel to the axis, therefore its reflection will pass through F (the principal focus). The two reflected rays meet at *a*. It can be shown that not only these two rays, but that *all* the reflections of the rays from the tip of the candle meet at (or about) *the same spot*.

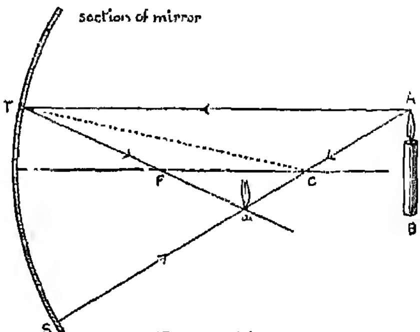


FIG. 50 (*a*).

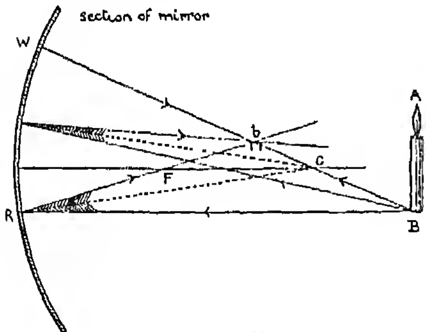


FIG. 50 (*b*).

Similarly, we can show that *all* the rays from *B* the

base of the candle, after being reflected from the mirror, proceed to b [Fig. 50 (b)], and that all the rays from portions between A and B proceed to the space between a and b. Consequently, an inverted image of AB is seen at ab. Look into any concave reflector. Your reflection appears upside down.

NOTES.—(i.) *The image* ab *is situated between the focus and the centre of curvature* [Fig. 50 (c)].

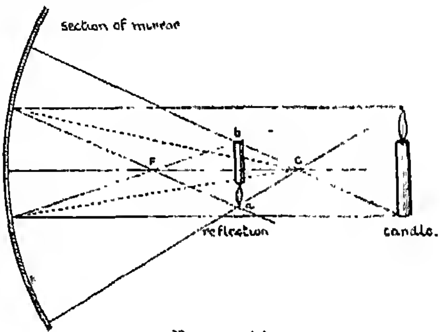


FIG. 50 (c).

(ii.) *In following diagram (b), do not forget that each incident ray and its reflected ray make* equal *angles with the normal through* C. *These equal angles have been lightly shaded to make this point clearer.*

SUMMARY OF CHAPTER X.

Spherical Mirrors.

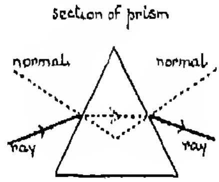
1. These are either **concave** or **convex** mirrors, according to whether the inner or outer surface is used for reflection.
2. The line from the centre of curvature to the vertex is called the principal axis.
3. All normals pass through the centre of curvature.
4. Parallel rays of light falling on a concave mirror are reflected back to the **principal focus**, situated half-way between thecentre of curvature and the vertex.
5. A concave mirror forms an **inverted** image of an object.

CHAPTER XI

PRISMS AND LENSES

35. **Refraction through Prism.**—You will remember in your former lessons on refraction that rays of light are bent *towards the normal* as they pass from air to water or glass, but are bent *away from the normal* as they pass from water or glass to air.

When a ray of light passes through a glass wedge (or prism, as it is called) it is doubly bent. The diagram (Fig. 51) shows its course.



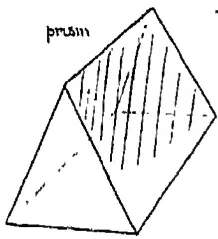


FIG. 51.

EXPERIMENT 45.—Stick a pin upright on a piece of drawing-paper, and place a glass prism, with its triangular end resting on the paper, so that on looking through the prism the pin can be seen. Without moving the position of the eye, fix another pin so that it appears to be immediately behind the first.

In *front* of the prism, place two more pins upright, and in such positions that they appear in line with the first two—that is, all four pins look as if they are in a straight line. Mark the position of the prism, and then remove it. Now look at the pins. It is evident that

they are by no means in a straight line, yet on replacing the prism in its former position, they again *appear* to be absolutely in line. This effect is due to refraction. The rays of light on passing through the prism in each case are bent out of their course towards the base. Fig. 52

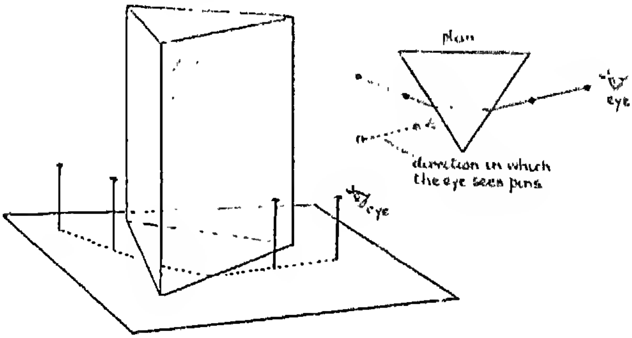


FIG. 52.

shows diagrammatically the position of the pins and the direction in which they appear to the eye.

EXPERIMENT 46.—Look at a candle-flame through the thinner part of a prism, arranged as in Fig. 53. Put a little salt in the flame to give it a bright yellow colour. The candle seems raised towards the edge of the prism. Refer again to the last experiment.

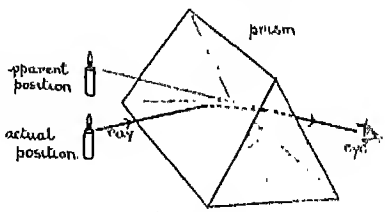


FIG. 53.

Here also the object (*i.e.*, the two pins) seemed to be brought nearer the edge of the prism.

EXPERIMENT 47.—Arrange the prism on a suitable stand, so that it can be rotated into different positions,

as indicated in Fig. 54. (For construction see Chapter XXX.).

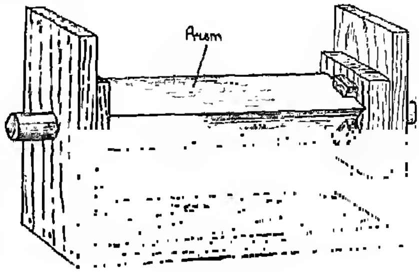


FIG. 54.

While looking at the appearance of the candle-flame through the prism, turn the latter slowly round. *What do you notice about the apparent height of the candle-flame?* There is a position in which it seems the least raised. This is called the position of **least deviation.**

36. **Lenses**—EXPERIMENT 48.—Hold an ordinary magnifying glass between your finger and thumb, and note—

(i.) That the surface is **curved.**

(ii.) That it is **thicker at the centre** than near the rim.

Such a curved piece of glass is called a lens, and

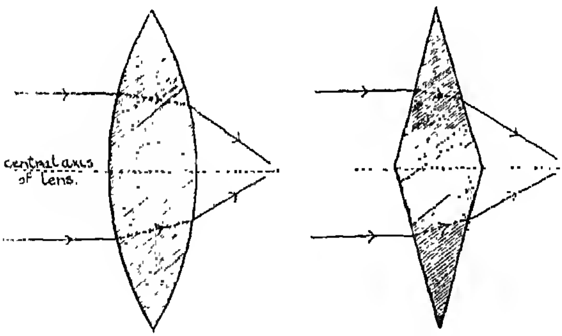


FIG. 55.

because this lens is **convex** on *both* outer surfaces it is called a **double convex lens.**

Draw a section of it. You will note a certain resemblance between this section and a section of two prisms with their bases together (see Fig. 55).

Now you have just learnt that rays of light falling upon a glass prism are bent towards the thickest part. *Does this apply also to the convex lens ?*

Hold the convex lens so that the sun's rays shine fully upon it. Place a sheet of paper on the side of the lens away from the sun. A bright spot of light is seen.

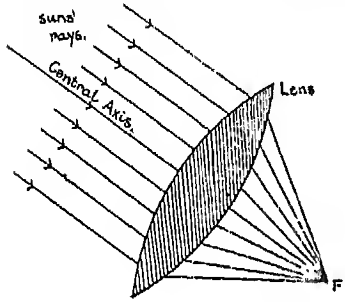


Fig. 56.

Move the paper backwards or forwards until the spot appears at its brightest. You have now found a spot (*F* in Fig. 56) which is the focus for the sun's rays passing through the lens —that is, the sun's rays which fall upon the lens *parallel* to each other are bent or refracted in such a way that they are now all directed towards one spot, the focus.

EXPERIMENT 49.—Focus the sun's rays again on the paper, and allow the bright spot to remain in exactly the same position for a minute or two. The paper will become *scorched* and perhaps even begin to *burn*. Evidently heat rays are also brought to the same focus.

37. **Concave Lenses** — EXPERIMENT 50. — Hold various lenses, one by one, between your finger and thumb, and select a lens which is *thinner* in the middle than at the rim.

Fig. 57 shows the section of such a lens, which is

called a **double concave** lens, because *both* its outer surfaces are concave.

Try to focus the sun's rays on a piece of paper by means of a concave lens. You cannot do it. That is because the rays of light, after passing through the lens, **diverge** from the central axis instead of coming to a focus there. The diagram indicates the course of the sun's rays as they pass through the glass and out on the other side. You will note that instead of proceeding *towards* a focus, the rays seem to come *from* a focus on the same side of the lens as the sun's rays.

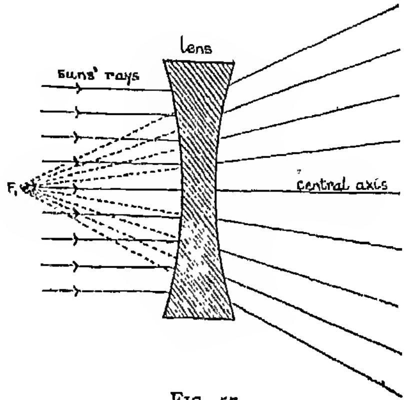


FIG. 57.

NOTE.—*It will be clearly seen that a ray of light falling on the lens along the central axis cannot be bent to either side, but will continue straight on. You should also know that* every *ray which passes* **through the centre of the lens** *continues its direction unchanged.*

38. **Various Forms of Lenses.**—Some lenses have one side quite flat, others have one concave and one convex surface, but you need not remember their names.

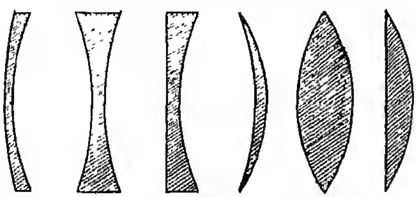


FIG. 58.

If a lens is *thicker*

at the centre than at the rim, the rays passing through it parallel to the axis can be brought to a focus, and the lens is called a converging lens (because the rays *converge* towards a point).

If a lens is *thinner* at the centre than at the rim, the rays passing through it parallel to the axis *diverge*, and the lens is a diverging lens.

SUMMARY OF CHAPTER XI.

Prisms.

1. When a ray of light passes through a glass prism it is refracted towards the base of the prism.

2. A candle-flame viewed through a glass prism seems raised.

Lenses.

3. Lenses are **convex** or **concave**, according to whether they are **thicker** or **thinner** at the *centre* than at the *rim*.

4. A **convex** lens can form a real image of an object, a **concave** lens cannot. The **focus** of a **convex** lens is the point to which parallel rays passing through the lens **converge**. The **focus** of a **concave** lens is the point from which parallel rays seem to **diverge** after passing through the lens.

CHAPTER XII

IMAGES FORMED BY LENSES

39. **Image formed by Convex Lenses**—EXPERIMENT 51.—Place a lighted candle about 18″ from a double convex lens and a screen on the other side of the lens (see Fig. 59). A suitable support for the lens and its construction is given in Chapter XXX.

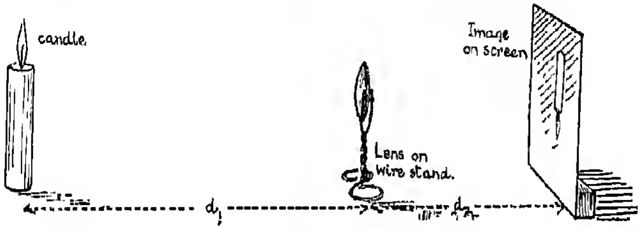


FIG. 59.

Move the screen backwards or forwards until a clear image of the candle is seen upon it.

(i.) Note that **the image is inverted.** To understand this, look at Fig. 60. On the left is shown a

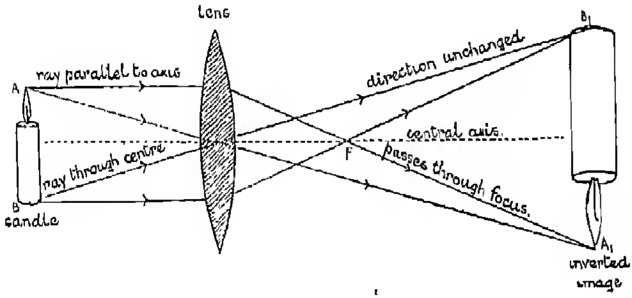


FIG. 60.

lighted candle. Many rays of light come from it, but we shall trace the course of a few only, those which are most convenient for our purpose. We know already—

(*a*) A ray, passing through the *centre of the lens*, does not change its direction.

(*b*) A ray, *parallel to the axis*, passes through the focus of the lens.

Two such rays have been drawn from the *tip* of the candle A, and they are found to meet again at A_1. Another two such rays have been drawn from the base of the candle; they meet at B_1, and if we were to trace the course of *every* ray from the candle they would meet between A_1 and B_1, forming an inverted image of the candle.

(ii.) Measure the distances d_1 and d_2. Move the candle further from the lens, and again place the screen to obtain a sharp image. Again measure the new distances d_1 and d_2 (see Fig. 59). Try other positions and prove that **the farther the candle from the lens the nearer the image.**

NOTES.—(i.) *You will now understand, with regard to any such lens, that* **for every position of the candle there is one corresponding position for the sharpest image.** *When this is obtained, the object is* **focussed** *on the screen. In photography, instead of moving the* **screen** *to and fro, the position of the lens is generally altered until the relation between the object, lens, and screen is the correct one.*

(ii.) *The bright spot of light obtained by focussing the sun's rays on a piece of paper is really a little image of the sun. The position of this bright spot is called the* **principal focus** *of the lens, and its distance from the lens is called the* **focal length** *of the lens.*

(iii.) Note the alteration in the size of the image as

the position of the candle is changed. Measure the heights of the object and image, and compare the ratio between them with that between d_1 and d_2.

Prove that—

$$\frac{\text{Size of object}}{\text{,, ,, image}} = \frac{\text{distance of object from lens}}{\text{,, ,, image ,, ,,}}.$$

NOTE.—*In taking a photograph, the object is much farther from the lens than the photographic plate or film, hence the image is small; but in the magic lantern the slide (= the object) is brought near to the lens. Consequently, the image on the screen, which is some distance away, is large.*

40. **The Magic Lantern.**—With the arrangement of Fig. 59 place a piece of glass with an ink design on it immediately in front of the candle. It is reproduced on the screen, but upside down. *How can we obtain a correct image?* By inverting the glass slide. This is the principle of the magic lantern. Examine, if possible, the school lantern. The lamp may be an incandescent burner, a limelight, or an electric light, but in each case a very powerful pair of lenses (called the **condenser**) is placed in front of the light to concentrate as many rays as possible on the slide. In *front* of the slide is the focussing lens which forms the image on the sheet.

41. **Magnifying Glass.**—So far, the object and the screen have not been placed nearer to the lens than its focal length, but if a convex lens is placed quite near to an object the result is different.

EXPERIMENT 52.—Bring the candle to a very short distance from the lens, and move the screen to various positions to try to obtain an image. None is formed on the screen. Look at Fig. 61; the rays from the candle, *when it is placed close to the lens*, diverge on

passing through the lens, and therefore cannot be focussed on a screen, but they *seem* to come from an image *behind* the candle. This image is called a virtual image of the candle. Remove the screen and look through the lens at the candle (Fig. 62). This virtual image can be perceived by the eye. Note that it is erect and magnified. The lens is now acting as an ordinary magnifying glass, such as many people use to examine specimens or to read small print.

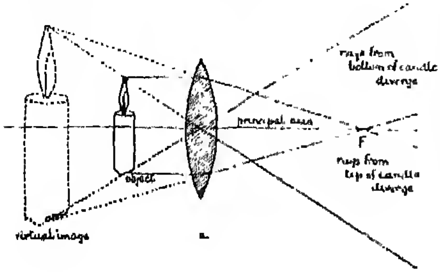


FIG. 61.

Move the lens slowly away from the candle, and note the changes in the image seen by the eye. It grows larger and larger, but at a certain distance the image becomes blurred and then vanishes. Still move the lens away and a tiny inverted image of the candle falls on the eye; this indicates that the candle is *outside* the focus of the lens.

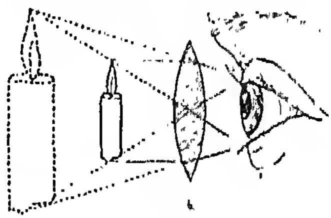


FIG. 62.

With a *convex* lens, when the object is at a distance from the lens—

(*a*) Less than the focal length, the image is virtual and erect.

(*b*) Greater than the focal length, the image is real and inverted.

42. **The Telescope.**—A telescope is an instrument by which we may see a **magnified image** of a *distant* object.

EXPERIMENT 53.—Place a candle at one end of a darkened room and a convex lens and a ground-glass screen at the other. Arrange the distance of the screen from the lens so that a clear image of the candle is

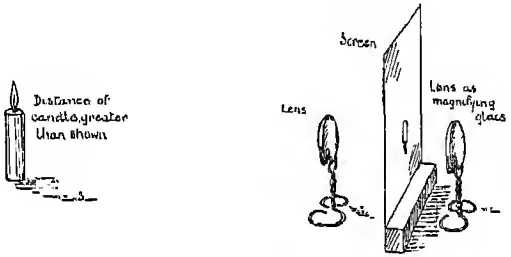


FIG. 63.

obtained upon it. Place another convex lens just behind the glass screen to act as a magnifying glass. On looking through this second lens, an enlargement of the image of the candle is seen. This also looks much *nearer* than the candle itself.

Take away the screen. Although now the image is not focussed on the screen, yet an image of the candle can still be seen on looking through the lens.

You have constructed a simple form of telescope. In the instrument itself, the lenses are enclosed in two tubes, one sliding inside the other, so that the distance between the lenses can be regulated.

The lens, which forms the image of the distant object, is called the **object-glass**. The smaller lens, through which we look, is called the **eye-piece**.

NOTES.—(i.) *The image seen in this form of telescope (called the* astronomical telescope *from its use in astronomy) is* inverted. *In good instruments, for viewing distant objects on land and sea,*

two more lenses are placed between the object-glass and the eye-piece, so that an erect *image may be seen.*

(ii.) *Since the objects viewed are distant, the image will be formed near the principal focus of the* object-glass. *The instrument-makers will be guided by the focal length of this lens in determining the length of tube that would be required.*

43. **The Opera-Glass or Binocular.**—Another form of telescope, much more frequently used than the astronomical telescope, is shown in Fig. 64. This instrument is known either as the opera-glass, from its use at theatres for seeing objects on the stage more distinctly, or as a binocular, because it has a pair of lenses, one for each eye.

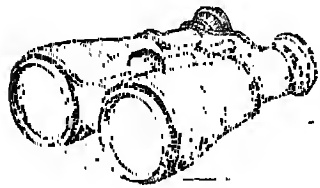


Fig. 64.

Examine one of these instruments. Note that—

(*a*) Two telescopes, one for each eye, are mounted on a frame side by side.

(*b*) The length is not great.

(*c*) The object-glass is double convex, the eye-piece is double concave.

(*d*) The focussing of the instrument on an object is brought about by turning a screw, which alters the distance between the eye-piece and the object-glass.

Experiment 54.—Focus a distant candle-flame by means of a convex lens on a screen. Place a *concave* lens of *short* focal length in *front* of the screen. (In Experiment 53, the magnifying lens was placed *behind* the screen.) An image cannot now be formed on the screen, because the rays which formerly converged to the image on the screen now diverge from the concave lens.

Remove the screen and look through the concave lens. An **upright**, nearer view of the object is seen.

NOTE.—*The concave lens of the opera-glass should be placed in front of the image formed by the object-glass at a distance equal to its focal length. The latter must therefore be much less than that of the object-glass.*

44. **Image formed by Concave Lens**—EXPERIMENT 55.—In Paragraph 39, a geometrical construction for finding the size and position of the **real image** formed by a **convex lens** was given.

A similar geometrical construction can be drawn to show the path of rays from an object after passing through a **concave lens**, although we already know from Experiment 50 that a *real* image cannot be formed by a *concave* lens.

Fig. 65 will help you to understand this. A concave

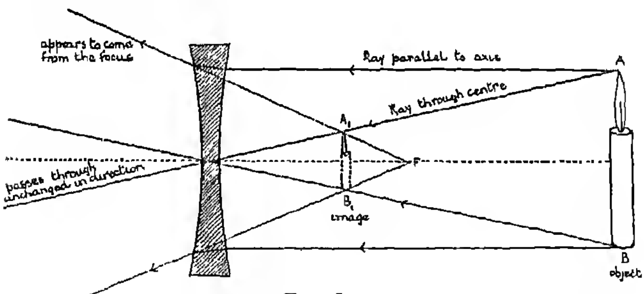


FIG. 65.

lens is placed in front of the candle AB. The refraction of the rays falling on the lens cause most of them to diverge and therefore they cannot form an image on the opposite side of the lens to the candle.

But you will notice that because of the divergence caused by the concave lens of the rays from the candle, *they seem to proceed from the position* A_1B_1. For this

reason the concave lens is said to form a virtual image at A_1B_1. To find its position, remember that rays—

(*a*) Through the centre of the lens pass on unchanged in direction.

(*b*) Parallel to the axis of the lens diverge from the focus of the lens.

In the diagram two such rays from the tip have been drawn, and the intersection of the diverging ray from the focus with the ray through the centre gives the position of A_1.

A similar construction gives the position of B_1. There is no need to draw the course of other rays from the candle, but if such were drawn, the image formed by them would help to complete the image of the candle between A_1 and B_1.

Notice that—

(i.) The image is smaller than the object.

(ii.) „ „ erect.

(iii.) $\dfrac{\text{Size of image}}{\text{,, ,, object}} = \dfrac{\text{distance of image from lens.}}{\text{,, ,, object ,, ,,}}$

Notes.—(i.) *If similar constructions are made for various positions of the candle and lens, you can prove that the image can never be as large as the object.*

(ii.) *When we view the candle through a concave lens, the rays of light fall on the eye as if they proceeded in straight lines from the virtual image* A_1B_1; *that is the reason we seem to see the candle at that spot.*

(iii.) *We saw that a* convex *lens can form a* real *image* (i.e., *one that can be received on a screen*) *when the object viewed is outside the focus of the lens, or a* virtual *image when it is nearer the lens than its focal length. A* concave *lens alone can only form a* virtual *image.*

SUMMARY OF CHAPTER XII.

Convex Lenses.

1. The image formed by a convex lens on a screen is **inverted.**

2. For every position of the *object* there is a corresponding position of the *image.*

3. The *farther* the object from the lens, the *nearer* the image to the focus.

4. The *size* of the clearest image depends on the distance of the object from the lens.

In the **camera** the screen is comparatively close and the image is small. For a **lantern** the screen is much farther off and the image large.

5. When a convex lens is held *very* near an object, a **virtual**, enlarged and erect image can be seen through the lens.

6. An **astronomical** or **field telescope** is a combination of a pair of convex lenses, the **object-glass** and the **eye-piece.**

Concave Lenses.

7. The image formed by a **concave** lens alone is **virtual, erect,** and smaller than the object.

8. In the **opera-glass,** or **binocular,** a convex lens is used for the object-glass, a concave lens of short focal length for the **eye-piece.**

Chapter XIII

THE EYE

45. **The Eye.**—On looking at a friend's eye, only the small portion of the eyeball between the eyelids can be seen, the greater part being embedded in a bony socket. Of the visible portion we notice—

(*a*) The main, outer coating, the **white of the eye.**

(*b*) The ring-shaped, coloured curtain, the **iris.** This is usually blue, brown, black or grey in colour.

(*c*) The dark, central opening, the **pupil,** through which light passes into the interior.

Over all these in front is a transparent coating, the **cornea.**

Just behind the iris and pupil is the **crystalline lens,** *a double convex lens,* made of a transparent, solid substance, acting just like a glass lens.

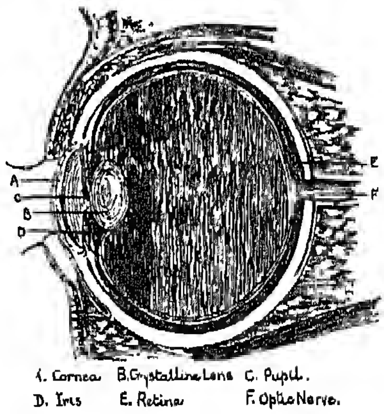


Fig. 66.

Examine the diagram of the eye given in Fig. 66, showing it in section. Note the position of cornea, iris, and lens. The space in the eye between the lens and cornea is filled with a watery liquid; the main cavity is also filled with a liquid, but more jelly-like in character.

The action of the eye resembles that of a camera. From the object, rays of light travel to the camera lens, and are focussed on a screen in the dark interior of the box. From the object seen by the eye, light rays pass through the crystalline lens and are focussed on the retina, the back portion of the interior of the eye. The retina is extremely sensitive to light, and all the delicate light and shade and the different colours of the image received by it are flashed to the brain by its special nerve, the optic nerve.

One important difference between the camera and the eye will soon be perceived. The photographer *focusses* the image by moving the lens slightly forward or backward. *How does the eye focus objects at different distances from the lens?*

It is evident that the distance of the lens from the back of the eye cannot be altered. But nature has overcome the difficulty in a wonderful way. Examine all the convex lenses you have. The focal length depends on the curvature of the lens, and you will find that a very *thick* lens has a *short* focal length, while a thin lens focusses an object at a much greater distance.

The eye-lens can be altered in thickness by the action of certain muscles, and if our eyes are in good order these muscles act quite naturally without our being aware of the action, and produce the exact amount of curvature to cause the image of the object, which is being viewed, to fall on the retina.

46. **Defective Eyes.**—The eye-lens can be altered in thickness only to a certain degree, and so we find people whose eye-balls are unusually long or short (from front to back) possess defective vision, because they are unable to produce the necessary curvature of the eye-lens for the image to be focussed on the retina.

NOTE.—*Before studying the remainder of this paragraph, it will be advisable to revise Experiment* 53 *on convex lenses, and to remember that with a* fixed *convex lens, the farther the object is moved from the lens, the nearer the screen must be brought to the focus of the lens to get a sharp image. For very distant objects, the screen must be placed at the focus of the lens.*

In **myopia**, or **short-sight**, the eye is too long from front to back. Consequently, while near objects can be focussed easily by the eye-lens, distant objects are

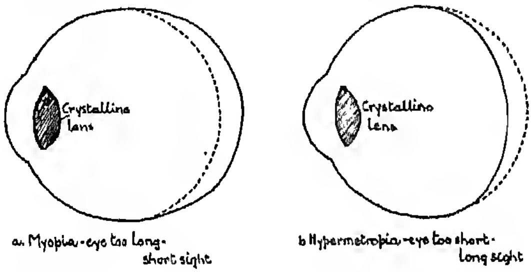


FIG. 67.

blurred. After the eye-lens has been made *as thin as possible*, the focus will not reach to the retina and consequently, the *distinct* image of a distant object will be formed in front of the retina and only a blurred image received by the retina itself.

So some method of securing a greater focal length must be found to remedy this defect. This is obtained by the use of a **concave** lens.

EXPERIMENT 56.—Focus the light from the sun, or a distant bright object by means of a **convex** lens on a screen. Place a **concave** lens (of a greater focal length than the convex lens) *just in front of* the convex lens and again focus. The screen must now be moved back. The focal length is increased by placing a concave lens with the convex lens.

NOTE.—*When a convex and a concave lens are placed together, the combination acts as a single lens. This will be of the same kind as the lens which has the* **shorter focal** *length.*

The above experiment will succeed only if the focal length of the concave lens is greater than that of the convex lens.

Shortsighted persons wear spectacles with concave lenses to aid the work of the lenses of the eyes, and the oculist determines with great care the exact strength of the lens to be supplied to give the best results.

In **long-sight**, or **hypermetropia**, the *distant* objects are clearly seen but *near* objects are blurred. This is caused by the retina being too *near* the lens, and the muscles of the eye being unable to make the eye-lens sufficiently curved to focus a near object on the retina. You can understand this by placing a candle in front of a convex lens and forming a distinct image on a screen. Now imagine that the screen in that position represents the retina of the normal (=perfect) eye. Move the screen a little towards the lens. The image is blurred and represents what is seen by persons suffering from **hypermetropia**. *How can it be remedied?* By using a thicker lens—that is, one with a shorter focal length. But suppose you are already using the thickest one you possess. Then use *two* convex lenses. Prove for yourself that a distinct image of the candle is obtained on the screen at a much nearer position to the lens when a combination of two convex lenses are used than when either is used separately.

Therefore, persons suffering from **hypermetropia** use spectacles with **convex** lenses in them.

NOTE.—*In many old people the muscles of the eye have become too weak to produce the curvature necessary for a correct focus. They, too, are supplied with convex spectacles to bring the image of the object within a certain range.*

SUMMARY OF CHAPTER XIII.

The Eye.

1. The crystalline lens of the eye, situated at the back of the central opening or pupil, focusses the image of the object looked at on the retina at the *back* of the eyeball.

2. Since the distance between the lens and the retina is fixed, in order to focus correctly objects at different distances from the eye, the curvature of the lens can be altered by the action of certain muscles.

3. In *defective* eyes the necessary curvature for a correct focus cannot always be obtained. Hence, for—

short-sight, *concave* spectacles are needed.
long-sight, *convex* „ „ „

Chapter XIV

FORMING A SPECTRUM

47. **Refraction through a Prism.**—In Experiment 46 you looked at a candle-flame through the edge of a glass prism, but you were advised to colour the flame by the addition of a little salt. Try the experiment again, but omit the salt. Notice that various colours can be seen through the prism, instead of the white light of the candle-flame. Let us examine this more carefully.

Experiment 57.—Cut an opening about 1″ long and ¼″ wide in a piece of stout cardboard. Cut two

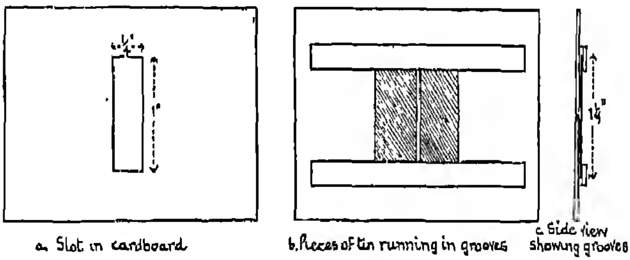


Fig. 68.

pieces of tin 1½″ long and ½″ wide, and arrange them to slide in a groove at the back of the card, as shown in the diagrams of Fig. 68. Nail the cardboard to a piece of wood so that it can stand upright. Bring the two pieces of tin very close together, so that a very narrow slit, with clean-cut edges, is obtained.

Place a strong, white light behind the slit and a

converging lens in front of the slit, and arrange a screen of white cardboard, so that a clear image of the slit is obtained on the screen [Fig. 69 (*a*)].

Interpose a glass prism (with its long edges parallel to the length of the slit) between the lens and the

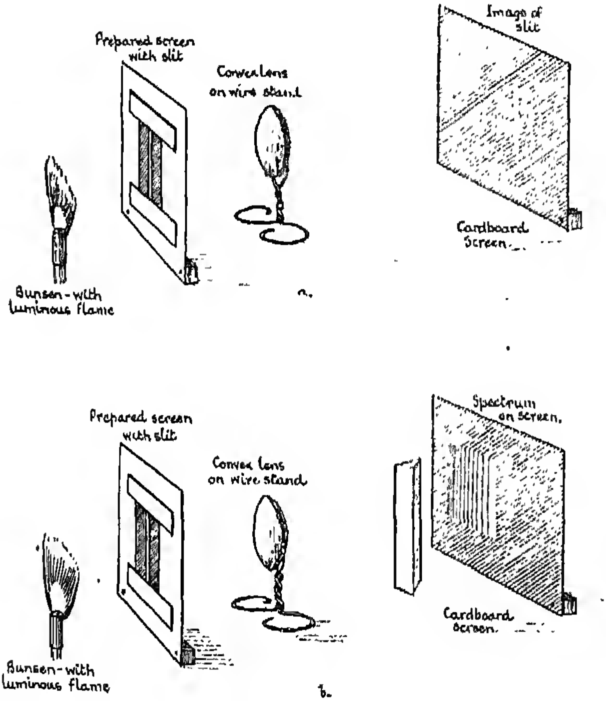


FIG. 69.

screen, so that the light passes through it before reaching the screen. Notice that—

(*a*) The image of the slit has moved.

(*b*) It is no longer white, but forms a band of colours ranging from red at one end to violet at the other.

This coloured image is called a **spectrum**. Write down the colours in their order. They are: red, orange, yellow, green, blue, indigo, violet—exactly similar to those of a **rainbow**.

NOTE.—*These experiments should be carried out in a thoroughly darkened room. If, however,* **a ray of strong sunlight** *is allowed to enter through a slit in a blind, it can be used instead of the gas-light to produce a spectrum and with much greater effect.*

When white light passes through a prism, each of these rays is **refracted**, *but not to the same extent*—that is, some of the rays are bent out of their path more than others. Look at the screen, and find which rays have moved their position most and which the least.

Slowly turn the prism round. This will alter the position of the coloured band to some extent, and you will find that the image is the *clearest* when it is *least* deviated.

EXPERIMENT 58.—Place a second prism similar to the first beside it, arranged as indicated in Fig. 70. The image in the screen is *white*. The colours have combined again.

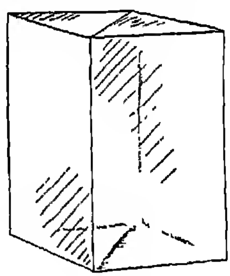


FIG. 70.

NOTES.—(i.) *This splitting-up of white light into several colours is usually termed* **dispersion**.

(ii.) *Since lenses refract light, the images formed by them are often tinged with colour due to dispersion. By using* two *lenses close together of different kinds of glass, and of suitable focal lengths, it is possible to lessen very considerably this defect. This is especially important in photography and for observations with field-glasses.*

(iii.) *Refraction and dispersion take place when light passes through a glass sphere or a globular water-bottle, and the spectrum colours can be distinguished if the light is strong.*

(iv.) *A drop of rain is approximately spherical in shape, and sunlight falling on myriads of them is refracted and dispersed, giving rise to the* rainbow, *which can be perceived by those in a certain position with regard to the sun and rain. A fountain produces a similar effect. If the observer and the sun are on the same side of the fountain, a rainbow can usually be seen.*

SUMMARY OF CHAPTER XIV.

A Spectrum.

1. When a beam of white light passes through a triangular glass prism, it—

   (*a*) Is refracted towards the base of the prism.
   (*b*) Forms a coloured band called a spectrum.

2. The colours of the **spectrum** are red, orange, yellow, green, blue, indigo, and violet.

3. White light is composed of the colours of the spectrum blended together. These are refracted to different extents when passed through a prism.

4. **Dispersion** (or breaking up of white light) occurs to some extent when white light passes through a lens or through a spherical glass bowl filled with water. Rainbows are caused in a similar way.

SECTION IV.—CHEMISTRY

CHAPTER XV

HOW MATTER IS BUILT UP

48. **Atoms and Molecules**—EXPERIMENT 59.—Take a piece of roll sulphur, grind and pound it until you have a very fine powder. Look at it through a magnifying glass and note that some particles are still larger than the rest. Separate these and grind the remainder into as fine a powder as possible.

Can this powder be divided into smaller fragments? The old Greeks thought that, even with the finest and most powerful machinery to help, there would be a limit to the division. They thought that every substance was granular—that is, built up of very minute particles, which are themselves indivisible, but which could cohere to form the larger particles seen by the eye. They called these particles which could not be broken up any further—atoms.

Although their idea of the composition of substances was almost forgotten for many centuries, it was revived and extended by a great chemist, **John Dalton**, of Manchester (born in 1766), and on this foundation has been built up by Dalton and other scientists a theory, which has lasted to the present time, of the construction of matter.

They regard the atom as the smallest particle of any **element**. By an *element* we mean a substance which

is composed of only *one kind* of atom. Sulphur, for instance, is an element; whatever we do to it, however small we grind it, we can only obtain sulphur. On the other hand, water is a **compound**, composed of *two kinds* of atoms linked together in some mysterious way—atoms of **oxygen** and **hydrogen**—and we have already found out how to separate the constituents of water by means of electricity.

What is the size of an atom? So small that the finest microscope in the world cannot detect it, yet so wonderful are the ways of modern science that atoms have been *weighed* and *measured*, and we are told that *a million could lie comfortably across the width of a hair.* It has been calculated that if a single drop of water were magnified to the size of the earth, each tiny particle being enlarged in proportion, the atoms would not appear larger than golf balls.

But, as a rule, these atoms do not exist alone; two or more join together to form a larger particle, a

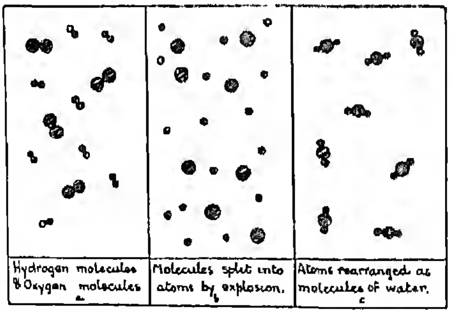


FIG. 71.

molecule. Sometimes when two substances are put together and suitably treated, the molecules of each are broken up and the atoms rearrange themselves, atoms of one substance uniting with those of the other to form

molecules of a compound. Thus when two volumes of hydrogen and one volume of oxygen are placed together in a strong glass vessel and a spark introduced into the mixture, *a violent explosion results;* the atoms in each oxygen and hydrogen molecule separate and then two hydrogen atoms attach themselves to one oxygen atom forming a molecule of water. That is why we write H_2O as the *symbol* for water.

NOTES.—(i.) *Fig.* 71 *represents diagrammatically what is supposed to happen:* (a) *shows* 4 *oxygen molecules and* 8 *hydrogen molecules, each composed of two atoms;* (b) *shows the breaking-up of the molecules as the result of the explosion which takes place when a spark is introduced into the mixture; while* (c) *shows the rearrangement into* 8 *molecules of water.*

(ii.) *Carbon dioxide is a compound. Each molecule of the gas is made up of one carbon atom combined with two oxygen atoms.*

49. **Cohesion.**—Cohesion was mentioned in Book I. as the force which held the particles of a substance together. We can now add to this statement. In a gas such as air, the molecules are free to move about; they rush hither and thither, often collide and rebound, but the molecules do not cling together; there is no cohesion. In a liquid, the molecules move much more slowly and slide and roll over each other, while in a solid they cling much more firmly together. Yet even in the hardest solid known to us, we should find that there is *some* room between the particles. A sponge will soak up water because it is porous, and a piece of *gold* will likewise soak up a quantity of *mercury.* Even the molecules of a solid are not still but are vibrating to and fro extremely rapidly.

You will understand the part that heat plays when it is applied to substances. It lessens the cohesion of solids, turning them into liquids; it increases the

movement of the molecules of liquids until it becomes so rapid that a gas is formed. Cold, on the other hand, *retards* the movements of gas molecules, and, if severe enough, will convert the gas into a liquid and then into a solid. Air itself can be liquefied by the action of extreme cold.

50. **Elements.**—At the present time more than 80 different substances are known which are called **elements** because they seem to be made up of only one kind of atom each. It is possible that some of the 80 may yet be found to be compounds which can be split into simpler bodies with quite different properties. For a long time, **soda**, **water**, and **lime** were looked upon as elements, but now we know that each is composed of more than one kind of atom.

SOME OF THE COMMON ELEMENTS.

Gases.		*Copper* (Cu)	63
Hydrogen (H) ..	1	*Gold* (Au)	197
Oxygen (O) ...	16	*Iron* (Fe)	56
Nitrogen (N) ...	14	*Lead* (Pb)	207
Chlorine (Cl) ...	35·5	*Magnesium* (Mg) ...	24
		Phosphorus (P) ...	31
Liquids.		*Potassium* (K) ...	39
Mercury (Hg) ...	200	*Platinum* (Pt) ...	195
Bromine (Br) ...	80	*Silver* (Ag)	107
		Silicon (Si)	28
Solids.		*Sodium* (Na) ...	23
Aluminium (Al) ...	27	Sulphur (S)	32
Calcium (Ca) ...	40	*Tin* (Sn)	119
Carbon (C) ...	12	*Zinc* (Zn)	65

The letters inside the brackets are the symbols by which a chemist denotes the substances. In some cases (*e.g.*, oxygen and aluminium) the symbol is taken from the letters of the English name of the substance,

but in others (*e.g.*, gold and lead) the symbol is chosen from the Latin name instead.

The figures given beside each element give the *relative weight* of an atom of each kind, compared with the weight of an atom of **hydrogen.**

The elements which are printed *in italics* are **metals**; the others are termed **non-metals.**

51. **Distribution of the Elements.**—Of the 80 elements only a few are found in any considerable quantity either in the earth's crust, the air above it, or in the animal and vegetable kingdom. **Oxygen,** which enters very largely into the constitution of rocks as well as air, stands first. **Silicon,** a non-metal, the basis of *sand;* **aluminium,** a metal derived from *clay;* the **nitrogen** of the air; the **carbon** of the animal and vegetable world; the **calcium** of *lime;* the **sodium** of *salt* also stand out prominently, but, apart from the commoner metals, the remainder are present only in small quantities.

Some of them, such as ytterbium and scandium, have never been heard of by ordinary folk, although a few of the scarce elements, such as **tantalum, osmium,** and **thorium,** have lately been pressed into man's service in the manufacture of incandescent mantles and filaments for the electric light.

The wonderful properties of **radium** have brought it to the public notice in startling fashion, although it is present as only one part in ten millions in the pitchblende from which it is extracted.

52. **Mixture and Compound**—EXPERIMENT 60.—Mix together equal quantities of well-powdered sulphur and very fine iron filings. A grey-green powder is the result, which to a casual glance appears to be composed of one substance only.

Divide the powder into 3 portions.

(*a*) Throw one portion into a beaker of water. Most of the sulphur floats or is suspended on the water, while the iron sinks to the bottom.

(*b*) Hold a magnet over the second portion. The iron filings will leap to the magnet and can be thus drawn away from the sulphur.

It will be seen from these experiments that the two substances are merely **mixed** together, that they can be separated, and that their properties have been unaltered by mixing.

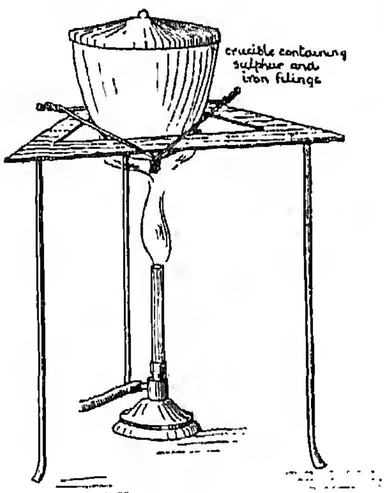


Fig 72.

(*c*) Now mix the third portion with more sulphur, place a small quantity in a crucible, cover with a lid, and heat strongly till all fumes of sulphur seem to have gone. A black mass remains. Grind it into small particles and test with the magnet. *There is no attraction;* clearly the particles are not iron, neither do they burn as sulphur does when heated. Yet this black mass was "built" up of particles of iron and sulphur.

We have, however, no longer a **mixture** of iron and sulphur, but a **chemical compound** of those two substances. They have **united** to form a new substance with different properties from either of them.

You could prove for yourself that iron and sulphur

unite only in certain proportions. If an excess of iron is taken, the right quantity for the amount of sulphur will unite, the rest will remain as iron. If an excess of sulphur is used, it will burn away.

The proportion by weight of each element in the same compound is fixed.

The following list, which gives three **compounds** and the **elements** which compose them, will show how different the properties of the substances formed by a chemical combination may be from those of the original substances.

Elements.	Compounds formed by their Union.
Hydrogen, a light, inflammable gas **Oxygen**, a gas which supports combustion	**Water**, a colourless, tasteless liquid, which quenches fire.
Iron, a heavy metal **Oxygen**, a gas	**Iron oxide** (or **rust**), a reddish powder.
Chlorine, a poisonous gas **Sodium**, a light metal which easily burns in air	**Salt**, a solid used in the preparation of food.

SUMMARY OF CHAPTER XV.

Atoms and Molecules.

1. **Atoms** are the smallest particles of any element. They rarely exist in a free state, but join to form molecules.

2. In an element the molecules are formed of the same kind of atom. In a **compound** the molecules are formed of different kinds of atoms. Every molecule of—

(*a*) Water contains two hydrogen atoms and one oxygen atom.

(*b*) **Carbon dioxide** contains two oxygen atoms and one carbon atom.

3. The molecules of a solid cohere strongly.
" " " liquid slide over one another, but still possess a little cohesion.
" " " gas possess no cohesion.
4. There are more than 80 elements known to scientists.
5. Two or more elements may unite to form a compound. The properties of a compound are usually quite different from those of the substances which form it.

CHAPTER XVI

SULPHUR

53. **Effect of Heating**—EXPERIMENT 61.—(*a*) Examine a roll of sulphur, noting its appearance, hardness, and brittleness. Grind a portion into powder, and place it in a test-tube. Heat the tube *very gently* over a Bunsen flame (the tube should not be allowed to touch the flame at first and should be constantly turned) until the sulphur is all melted. Note the pale amber colour of the liquid. Continue heating, and watch the changes that take place. The liquid darkens and thickens until the tube can be inverted without the contents falling out. When the liquid boils, a yellowish-brown vapour is given off, which condenses to a yellow powder called **flowers of sulphur** on the side of the tube.

(*b*) Pour some boiling sulphur in a thin stream into water. The sulphur assumes the solid state again, but in a **different form**; it is **plastic**—that is, it can be worked between the fingers. On standing for a few days, it turns back again to the ordinary, yellow, brittle variety of sulphur.

How it is Obtained.—Sulphur occurs in a *free* state chiefly in volcanic districts, but *combined* with other elements it is found all over the world. Even our bodies contain a certain amount of sulphur in combination.

In Sicily, from which we obtain large supplies, the free sulphur is mixed with earthy impurities, from which it is separated by first stacking the lumps in

brick kilns with a sloping floor and allowing part of the sulphur to burn. This gives out sufficient heat to melt the rest, which flows away through openings at the bottom. The sulphur, which is thus collected, is then distilled from iron retorts into a brick chamber. The first portion of vapour coming over condenses on the walls as flowers of sulphur, but, as the chamber gets warmer, the remaining vapour cools less rapidly, and forms a liquid at the bottom of the chamber, and is run off into moulds.

54. **Sulphur Dioxide.**—In the lesson on Oxygen (Book II., Chapter XV.) we found that sulphur, when burnt in air or oxygen, produces an oxide of sulphur, which is very soluble in water, forming an acid solution (see Fig. 73).

FIG. 73.

This oxide of sulphur is called sulphur dioxide, because in its formation two atoms of oxygen have attached themselves to each atom of sulphur.

EXPERIMENT 62.—Sulphur dioxide can also be prepared as follows: Fit up the apparatus shown in Fig. 74 (*a*). Place some copper foil or turnings in the flask, and cover with *strong* sulphuric acid. Heat the flask very cautiously, and as soon as the gas begins to come over remove the flame, *as the action of the acid on the copper will then produce enough heat to carry it on.*

Collect two or three jars by downward displacement, as it is heavier than air, and is too soluble to be collected over water. Cover each jar of gas collected with a well-greased glass plate.

NOTE.—*When sufficient gas has been obtained, attach a funnel to the delivery-tube, and allow this to dip just under the surface of some water in a large beaker [see Fig. 74 (b)]. The gas will bubble into the water instead of filling the room with choking fumes, and the wide mouth of the funnel will prevent the water from rushing back into the flask when the action ceases.*

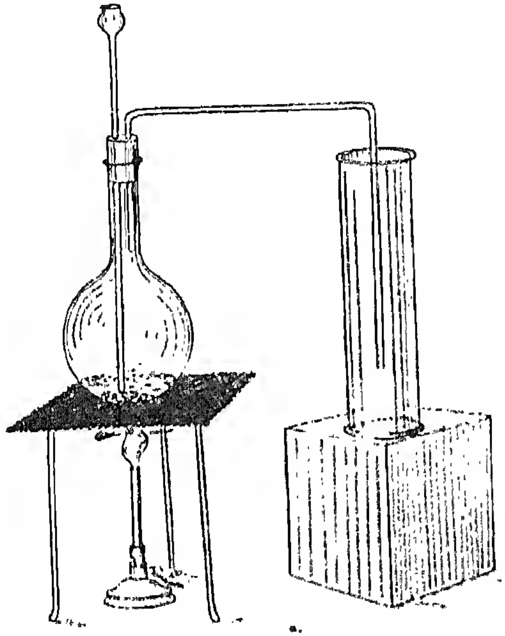


FIG. 74 (a).

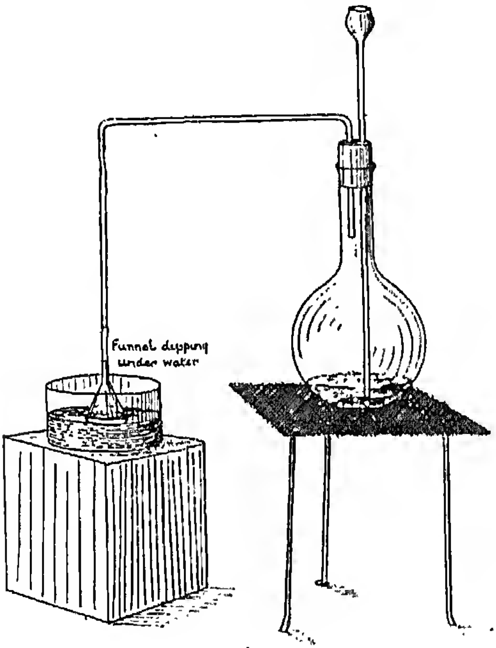
Note the colour and smell of the gas. Again test for solubility by inverting a jar of gas, and placing its mouth under water. On removing the glass disc, the water rises in the jar as the gas is dissolved.

Plunge a lighted taper into a jar of the gas. Sulphur dioxide neither burns nor allows the taper to burn.

Put some leaves or coloured flowers into the damp

gas or its solution. They gradually lose their colour. Sulphur dioxide is a **bleaching agent**, and is used to bleach materials such as **straw, silk**, and **sponge**, that would be injured by stronger bleaching chemicals.

55. **Acids derived from Sulphur** — EXPERIMENT 63.—Pour a little water into another jar of



b.
FIG. 74 (*b*).

sulphur dioxide, and prove by means of litmus that an *acid solution* has been formed. The acid is *not* the well-known **sulphuric acid** or **oil of vitriol**, but an acid not so strong in its effects, called **sulphurous acid**.

Sulphuric acid can also be prepared from sulphur by a special process not easy for a boy to carry out.

Let us try to understand the difference between the two acids. A molecule of sulphur dioxide is represented by SO_2, because it is formed by two atoms of oxygen attaching themselves to one atom of sulphur. A molecule of water is represented by H_2O. When sulphur dioxide dissolves in water, each molecule of the former attaches itself to one of the latter to form a bigger molecule of sulphurous acid. Thus—

$$SO_2 \quad + \quad H_2O \quad = \quad H_2SO_3$$

Sulphur dioxide added to water forms sulphurous acid.

But it is possible for sulphur dioxide by the aid of certain substances to take up another atom of oxygen, and then with the addition of water sulphuric acid is formed.

$$SO_2 \quad + \quad O \quad + H_2O \quad = \quad H_2SO_4$$

Sulphur dioxide combined with oxygen and water forms sulphuric acid.

56. **Sulphuric Acid**—EXPERIMENT 64.—Partly fill a very small beaker with water, and into it pour very slowly some strong sulphuric acid. Note that the temperature rises, until, when an equal bulk of each has been mixed, the beaker becomes quite hot. (*Never pour water into the strong acid.*)

Strong sulphuric acid has an affinity (that is, a liking) for water, and if exposed to the air will abstract water from the air itself. This can be shown by a gradual increase in the volume of the acid.

EXPERIMENT 65.—Place some paper, sugar, and shavings in a basin, and pour a little concentrated sulphuric acid on them. They all become charred. Each is composed of the three elements, carbon, hydrogen, and oxygen. The acid extracts the two latter in the form of water and leaves the carbon.

EXPERIMENT 66. — (*a*) Repeat Experiment 79, Book II., of placing some pieces of zinc in a test-tube,

and pouring in some *dilute* sulphuric acid. You know already that hydrogen will be given off. When the action has ceased, filter the contents of the test-tube, collecting the clear filtrate in an evaporating-dish.

Evaporate to dryness in a dish placed on a sand-bath or wire-gauze over a small flame. Examine the solid left. It is a salt called **zinc sulphate.** Try to understand the following equation:

Zn	+	H_2SO_4 (dilute) =	H_2	+	$ZnSO_4$
Zinc acted upon by		(dilute sulphuric acid) yields	hydrogen	and	zinc sulphate.

You will notice that the zinc has turned out the hydrogen from the sulphuric acid and taken its place.

(*b*) Try the action of dilute sulphuric acid on iron. A similar result follows, but now the crystalline salt obtained after evaporation is **iron sulphate,** and is green in colour.

(*c*) Prove that dilute sulphuric acid will not attack copper. We saw from Experiment 62 that on *heating* strong sulphuric acid and copper, sulphur dioxide is given off, not hydrogen.

The copper breaks up the acid in a different way from zinc.

Cu	+ $2H_2SO_4$ =	SO_2	+	$CuSO_4$	+ $2H_2O$
Copper and	(sulphuric acid) yield	(sulphur dioxide)	with	(copper sulphate)	and water.

Note that all the atoms represented on the left side of the equation are accounted for on the right side also.

(*d*) Pour off the liquid contents of the flask used for preparing the sulphur dioxide, add some warm water, stir, and filter. Heat the filtrate to half its bulk in an evaporating basin, and allow to cool. **Blue crystals of copper sulphate** will probably separate out. (It may

be necessary to evaporate more water before this succeeds.)

NOTE.—*Sulphur is largely used in the manufacture of matches and black gunpowder, and in various rubber preparations, such as vulcanized rubber. It is also used in medicine. After cases of fever, rooms are often disinfected by burning sulphur in them, the beneficial work being done by the sulphur dioxide produced.*

SUMMARY OF CHAPTER XVI.

Sulphur.

1. Sulphur is a yellow solid occurring—
   (*a*) In a free state in volcanic districts.
   (*b*) Combined with metals in nearly every part of the world.

2. It melts, when heated, to an amber-coloured liquid, which darkens on further heating, and finally boils, giving a yellow-brown vapour.

3. Sulphur burns in air or oxygen to form **sulphur dioxide**.

4. Sulphur dioxide—
   (*a*) Is a gas **heavier than air**.
   (*b*) Does not burn nor support combustion.
   (*c*) Is a strong **bleaching agent**.
   (*d*) Dissolves in water to form an acid solution—**sulphurous acid**.

5. **Sulphuric acid** contains one atom more of oxygen to each molecule than sulphurous acid.
   (*a*) It will abstract moisture from the air.
   (*b*) When poured on paper, sugar, and wood, these substances are **charred**.

6. Dilute sulphuric acid acts on zinc, and **hydrogen gas** is given off.

Strong sulphuric acid *heated* with copper sets free **sulphur dioxide**.

CHAPTER XVII

COMMON SALT

57. **Occurrence and Preparation.**—Occurring in the sea, in salt-mines, and in brine springs, salt has been known to mankind from time immemorial. In Cheshire salt is both mined and pumped up as brine. From the brine the salt is obtained by evaporation, and on the size of the pans and the temperature at which the liquid is kept depends the fineness of the salt which settles at the bottom of the evaporating pans.

Evaporation of the brine in *small* pans and at a *high* temperature produces fine table-salt, but when the evaporation is carried out in *large* pans and at a *moderate* temperature, bay-salt, coarse in grain and principally used for curing fish, is obtained.

Examination of Salt—EXPERIMENT 67.—(*a*) Heat some salt in a dry test-tube or in a crucible. It does not melt but cakes together.

(*b*) Heat some in a flame on a piece of platinum wire, or throw some salt into the colourless flame of a Bunsen burner. Note the yellow colour of the flame.

(*c*) Dissolve as much salt as possible in a quantity of water and thus form brine. Gently warm the solution, and test whether the hot water will dissolve any more salt.

(*d*) Evaporate the solution until a layer of salt forms at the bottom of the dish.

(*e*) Examine salt-crystals under a strong magnifying glass. They are tiny cubes.

58. **Composition of Salt.**—*What is common salt? Is it an element which cannot be broken up into other substances, or is it a compound?* Here again electricity comes to the aid of the scientist. If two *carbon* electrodes are allowed to dip into *fused* salt and a strong current passed through the salt, a greenish-yellow gas called **chlorine** is given off at one pole and tiny globules of a white silvery metal called **sodium** are given off at the other.

Sodium is rarely seen except in chemical laboratories. It is lighter than water, which it readily attacks as soon as the two substances come in contact. The sodium unites with part of the water to form **caustic soda** solution, but sets free some of the **hydrogen** which escapes into the air. To show this a piece of sodium is usually placed inside a piece of lead tube (closed at one end) to weight it and dropped into water in a dish. Over the tube, a glass jar, filled with water, is inverted, and held or secured in some suitable way (see Fig. 75). The hydrogen rises as a stream of bubbles into the jar. If some *red* litmus is poured into the dish, it will be turned *blue*, since the caustic soda solution formed there is an **alkali**.

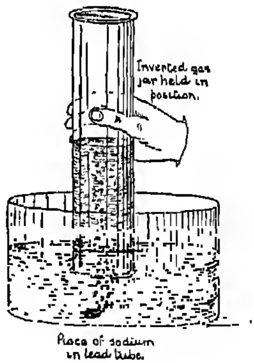


FIG. 75.

NOTE.—*Sodium rapidly rusts in air, forming an oxide of sodium. It is therefore usually kept under naphtha.*

EXPERIMENT 68.—Set up the apparatus used for the electrolysis of water (see Fig. 76), but use this time

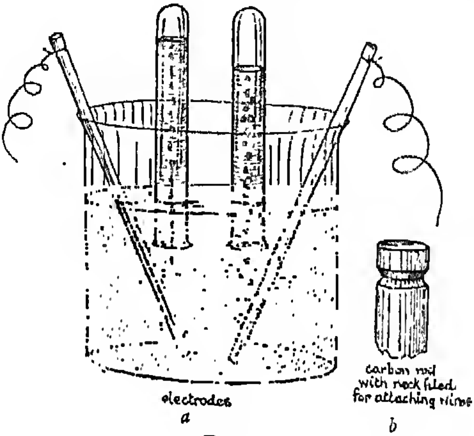


FIG. 76.

a solution of salt. Pass a current from two or three cells in series through the solution. Chlorine will be given off at one pole, but sodium will not appear at the other, because the instant it is formed it attacks the water and forms a solution of caustic soda. In doing so, it gives off hydrogen, as explained above.

These two gases may be collected in test-tubes and examined.

A more suitable apparatus is shown in Fig. 77. Two pieces of carbon are passed tightly through a large cork, filed to fit the sides of a large funnel. The bared ends of two lengths of insulated copper wire

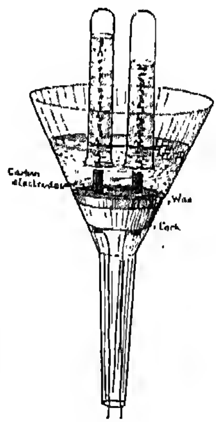


FIG. 77.

are attached to the lower ends of the carbons, and passed through the tube of the funnel.

When the cork is in position, melted paraffin wax is poured over it to the depth of at least ¼″ until it is quite watertight. Care must be taken that the wires are well insulated from each other. This may be done by dipping them in paraffin-wax, except the portions touching the carbons.

Note the colour and peculiar, choking smell of the **chlorine**. *Do not inhale it.* **It is poisonous**, and was largely used in **poison gas** during the Great War.

NOTES.—(i.) *If the solution is tinted with red litmus at the beginning, the formation of* **caustic soda**, *which is an* **alkali**, *can be seen by the blue colour around the pole from which hydrogen is given off.*

(ii.) *The chlorine may not appear immediately the current is switched on, because carbon will absorb a certain amount of it.* **Charcoal** *will absorb over* 70 *times its own volume of chlorine, and was therefore used as* one *of the chemicals in the* **respirators** *worn by the troops during a gas attack.*

(iii.) *A molecule of common salt is formed by the union of an atom of sodium with an atom of chlorine. It is often written down as* NaCl. (*From your list of elements you will see that* Na *is the symbol for sodium,* Cl *that for chlorine.*) *Its chemical name is* **sodium chloride**.

59. **Hydrochloric Acid**—EXPERIMENT 69.—Fit up the apparatus shown in Fig. 78. Place some common salt in the flask, and pour down the thistle funnel a little **strong sulphuric acid**. Add slowly until the salt is covered with the acid. See that the end of the thistle funnel dips into the liquid. **Warm gently**, and collect the gas given off by **downward displacement**.

As each jar is filled, cover it with a greased plate. When sufficient gas has been collected, attach a funnel

to the end of the delivery tube, as in Experiment 62 and let it just dip into water.

The gas collected is called hydrochloric acid gas.

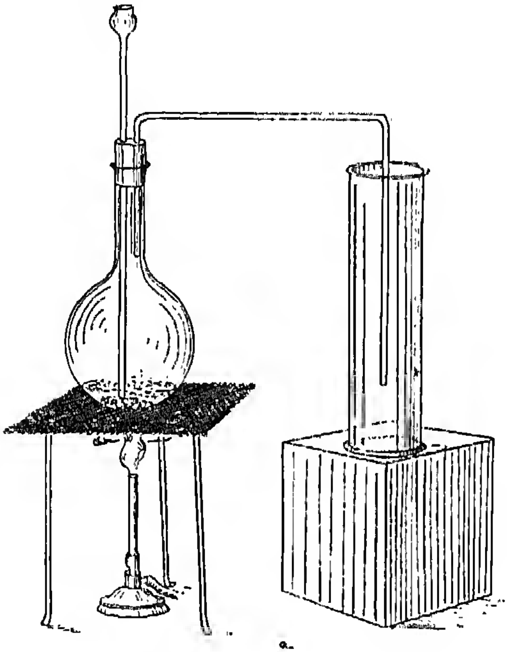


FIG. 78.

EXPERIMENT 70.—(*a*) Raise the glass plate from a jar, and notice that the gas fumes strongly. Smell it *cautiously*; it is pungent and suffocating.

(*b*) Place a lighted taper into a jar of the gas. It is extinguished. The gas neither burns nor supports combustion.

(*c*) Moisten the blue litmus paper, and hold it in the gas. It immediately turns *red*, showing that the gas is acid.

(*d*) Invert a jar of gas, so that its mouth dips below the surface of some water. Remove the glass plate. The water rushes in, taking the place of the gas, which it rapidly dissolves.

(*e*) Pour a few drops of strong **ammonia** solution into a gas jar, shake the jar, and pour away the liquid. Quickly invert a jar of hydrochloric acid gas over this jar, and remove the plate. **Dense white fumes are seen,** which settle on the sides as a powder. The ammonia gas and the hydrochloric acid gas have combined, and **sal-ammoniac,** or **ammonium chloride,** is formed as a white powder.

EXPERIMENT 71.—Repeat a former experiment of adding some hydrochloric acid to zinc and iron. **Hydrogen** is given off. Filter the contents of the test-tubes, evaporate the filtrates, and thus obtain the two salts formed.

Zinc + hydrochloric acid = hydrogen + zinc chloride.
Iron + „ „ = „ + iron chloride.

You can see that *hydrogen* must be a constituent of hydrochloric acid.

EXPERIMENT 72.—Place a small quantity of **manganese dioxide** in a test-tube, and pour in some strong **hydrochloric acid.** Gently warm the mixture. **Chlorine** is given off; you recognize its peculiar smell. Evidently chlorine also is a constituent of the acid.

Hydrochloric acid gas is a combination of **hydrogen** and **chlorine.** Its symbol is HCl.

NOTES.—(i.) *The available oxygen in the manganese dioxide seizes upon the hydrogen, thus setting the chlorine free.*

(ii.) *Chlorine can also be obtained by heating a mixture of* **salt, sulphuric acid,** *and* **manganese dioxide.**

(iii.) *Unless under very strict supervision, scholars should not prepare chlorine.*

60. **Bleaching-Powder**—EXPERIMENT 73.—Hold a piece of moist blue litmus-paper in the mouth of the test-tube from which chlorine is issuing. It first turns *red*, and then loses its colour.

Chlorine is a powerful bleaching agent of any vegetable colouring matter, such as litmus, red and black inks (but *not* printers' ink made of lampblack), the colours of flowers and leaves, indigo, and other vegetable dyes.

For commercial purposes, the chlorine is absorbed by lime, forming bleaching-powder. The material to be bleached is steeped in a dilute solution of bleaching-powder, and afterwards in dilute acid. The latter sets the chlorine free within the fibres, and thus the material is evenly bleached.

SUMMARY OF CHAPTER XVII.

Salt.

1. Salt has been known from very ancient times. It is found as a solid in the earth, and also in solution in the sea. From the latter it is obtained by evaporation.

2. Salt crystallizes in tiny cubes.

3. Salt sprinkled on a flame imparts a yellow colour to it.

4. A molecule of salt is composed of one atom of **chlorine** and one atom of **sodium.**

5. Sodium is a light metal which attacks water, giving off **hydrogen** and forming **caustic soda.**

Chlorine.

6. Chlorine is a highly-poisonous gas, heavier than air. It can be prepared by the electrolysis of brine.

7. It is a strong **bleaching agent.** For this purpose, it is usually absorbed in lime, forming **bleaching-powder.**

Hydrochloric Acid.

8. This acid is formed by heating a mixture of **salt** and **sulphuric acid.**

9. It is a fuming gas, with a strong, pungent smell. It will not burn nor support combustion. It dissolves readily in water, forming the liquid we call **hydrochloric acid.**

Chapter XVIII

I. AMMONIA

61. **How Obtained.**—Everyone is acquainted with the peculiar, pungent smell of **smelling-salts**, and probably everyone knows that the smell is due to the escape of a gas called **ammonia**. It is given off when meat, bread, leather, horn and many other animal and vegetable substances are strongly heated, and can often be detected near decaying animal refuse.

The old name for its solution in water was **spirit of hartshorn**, which indicates how it was produced.

Most of our ammonia to-day is obtained from the "gas-works" from the tarry liquid produced by heating coal.

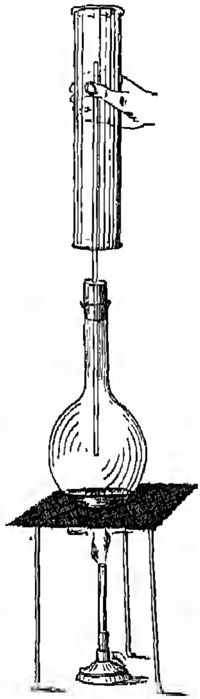


Fig. 79.

62. **Preparation** — Experiment 74.—Place some **sal-ammoniac** mixed with twice the quantity of **quick-lime** or **slaked lime** in a flask fitted with a cork and delivery tube as shown. Heat the flask *gently*, and the gas will be given off very quickly. To collect it, hold or support a gas jar *over* the end of the long tube, as shown in Fig. 79, for ammonia *is only about half as heavy as air* and should

be collected by **upward displacement.** When the jar is full—this can be detected by holding a red litmus paper near the mouth—remove it, *keeping the mouth downward*, place a second jar in position, and then stand the first jar, still inverted, on a glass plate.

63. **Properties**—EXPERIMENT 75.—(*a*) Hold a jar of the gas, mouth downward, and push into it a lighted taper. The taper is **extinguished**, but on looking carefully, a pale, yellow flame may be seen at the mouth of the jar.

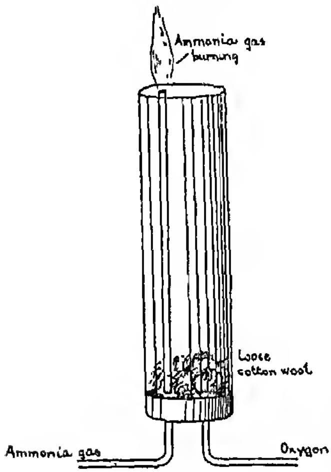


FIG. 80.

Ammonia gas will burn in *warm* air or in **oxygen.** An apparatus to show this can be fitted up, as indicated in Fig. 80. A lamp chimney is fitted with a cork, through which pass two delivery tubes for the gases. The oxygen tube can be connected directly with a test-tube or flask in which **potassium chlorate** and **manganese dioxide** are being heated.

(*b*) Place a jar of the gas with the mouth under water, and remove the glass disc. The water rushes in, almost with violence, so quickly does the water *dissolve* the gas and take its place. This experiment might be varied by filling a flask with ammonia gas, as suggested in Fig. 81 (*a*), then inserting a plug at the outlet, and clipping the rubber tubing at the bottom of the long tube. The apparatus is then placed in a trough of water, as shown in Fig. 81 (*b*), and the rubber tubing

removed. Water slowly rises up the long tube as it dissolves the gas until it reaches the top, when the process becomes very rapid and a miniature fountain is formed. The experiment is made more interesting if

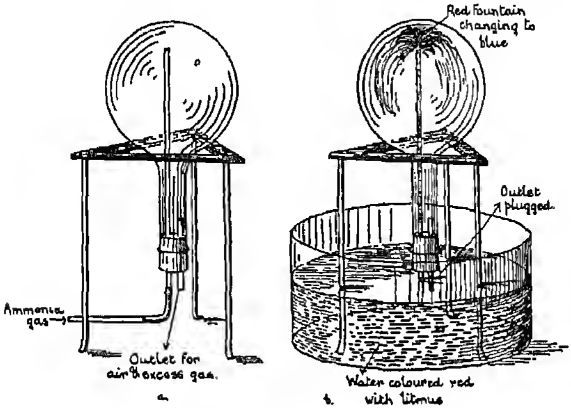


FIG. 81.

the water in the trough is coloured *red* with litmus. This changes to blue in the flask, showing that **ammonia is an alkali.**

64. **Composition of Ammonia.**—Ammonia gas is a compound of **nitrogen** and **hydrogen.**

This has been proved—

(i.) By thoroughly drying ammonia gas, and burning it in pure *dry* oxygen, using a similar apparatus to that in Fig. 80. If a *dry* gas jar is held over the flame, drops of **water** collect on the sides of the jar, showing that **hydrogen** is present.

(ii.) By passing ammonia gas over heated **copper oxide,** as shown in Fig. 82. The **hydrogen** in the ammonia unites with the **oxygen** of the copper oxide, forming water-vapour, which condenses in the water of

the trough, while the **nitrogen** passes on and can be collected in gas jars.

During the experiment the *black* oxide turns to reddish-brown copper.

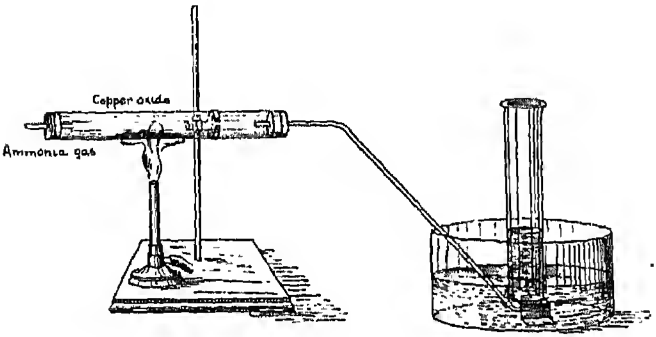


FIG. 82.

The ammonia and copper oxide yield water, nitrogen, and copper. It has been found that one molecule of ammonia contains one atom of nitrogen and three of hydrogen. Its formula is NH_3.

II. ACIDS AND BASES

65. **Oxides.**—In your lessons you have become acquainted with several oxides, and found that *some* of them dissolved in water to form **acids**. But not *all* of them. Red lead and mercuric oxide, for instance, are not soluble, neither are they at all acid. On examining the oxides that formed acids you will observe that they were derived from **non-metals**, such as **sulphur**, **carbon**, and **phosphorus**.

Most of the **oxides of metals** are insoluble, and do not act on water at all, except those of a certain group, including **sodium**, **potassium**, and **calcium**. The

oxides of these metals act on water, but instead of forming *acids* they form **alkalis.**

Sodium oxide + water form **caustic soda**, the formula for which is NaOH.

Potassium oxide + water form **caustic potash**, the formula for which is KOH.

Calcium oxide (lime) + water form **slaked lime**, the formula for which is CaO_2H_2.

66. **Salts.**—In general, we find that **metals, metallic oxides**, and **alkalis** unite with **acids** to form **salts.** In several cases you have already obtained these salts.

The salts obtained from—

Hydrochloric	acid	are	called	**chlorides.**
Sulphuric	,,	,,	,,	**sulphates.**
Nitric	,,	,,	,,	**nitrates.**
Carbonic	,,	,,	,,	**carbonates.**

Oxides or alkalis which **unite** with acids in this way are called **bases.**

67. **Ammonium Salts.**—We saw that **ammonia** dissolved readily in water to form an **alkaline** solution, and that **ammonia gas** united with hydrochloric acid gas, forming a white powder—a salt, called **sal-ammoniac.**

Therefore **ammonia**, although not a metallic oxide, acts as a base. If ammonia, either in solution or as a gas, is passed into sulphuric acid, it will gradually *neutralize* it. If the solution is evaporated, ammonium sulphate will be obtained. This is a *salt* formed by the union of the *base* ammonia and an *acid.*

SUMMARY OF CHAPTER XVIII.

Ammonia.

1. Ammonia is a light gas with a pungent smell. It is produced when animal and vegetable substances are burned or decay.

2. It is usually prepared by heating **sal-ammoniac** with lime.

3. It burns with a very pale flame, but does not support combustion. It is extremely soluble in water.

4. The molecule of ammonia has been proved to contain one atom of **nitrogen** combined with **three** atoms of **hydrogen**.

Acids and Bases.

5. Many of the **oxides of non-metals** (*e.g.*, carbon, phosphorus, and sulphur) dissolve in water, forming an acid solution.

Many of the **oxides of metals** are **insoluble** and neutral to litmus.

The **oxides** of certain metals, such as sodium, potassium, and calcium, dissolve in water to form **alkalis**.

6. In many cases **metals**, **metallic oxides**, and **alkalis** unite chemically with **acids** to form **salts**.

7. **Salts** are called **chlorides**, **sulphates**, **nitrates**, **carbonates**, etc., according to the acid forming them.

8. Ammonia, though not an oxide, acts as a **base**, and will combine with **acids** to form **ammonium salts**.

Chapter XIX

SOME ORGANIC SUBSTANCES

68. **Meaning of "Organic."**—From animal and vegetable material, we may obtain many substances—fat, oil, sugar, starch, and alcohol are only a very few of them. It has been proved that almost the whole of them are composed of **carbon, hydrogen, oxygen,** and **nitrogen** only—other elements taking a very small share. Many also contain no nitrogen. The name, **organic compounds**, was given to them because they were derived from living **organisms.** Some of these bodies are **acids,** others are **alkalis,** whilst others are **salts,** formed like common salt, by the action of an acid on an alkali.

69. **Sugar.**—This substance is composed of **carbon, hydrogen,** and **oxygen,** and although there are several kinds of sugars, the number of hydrogen atoms in every molecule is always twice that of the oxygen atoms.

Cane-sugar is obtained by crushing between heavy rollers, the stems of the sugar-cane, which is grown in hot countries. The juice is boiled with a small quantity of lime, which causes many impurities to separate out. These are removed, and the remaining solution boiled with animal charcoal to decolorize it, and filtered. It is then evaporated until crystal sugar begins to form. On cooling, a mass of crystals is deposited. From the liquids left in the pans, molasses and syrup are obtained.

The sugar obtained from the sugar-beet, largely grown in France and Germany, is exactly the same kind as cane-sugar.

EXPERIMENT 76.—(*a*) Test a solution of ordinary sugar with litmus. It is neutral.

(*b*) Heat some sugar until it just melts. Allow it to cool. It has lost its crystalline appearance. "Barley-sugar" has been formed.

(*c*) Heat some sugar until it turns to a brown sticky mass. This is caramel, or burnt sugar, and is used for colouring gravies.

(*d*) Repeat the experiment of adding a few drops of strong sulphuric acid to some sugar in a dish. Note the charred substances left. The acid takes away the hydrogen and oxygen as water, leaving the carbon.

Grape-sugar (glucose) occurs in honey and many fruits, especially in grapes. In raisins it can be found as small, brownish lumps. Though not quite as sweet as cane-sugar, it is used extensively for brewing purposes, and for making sweets.

Milk-sugar occurs in the milk of animals.

EXPERIMENT 77.—Add some rennet to some cow's milk. Curds separate out at the top, and milk-sugar remains in solution. (From the curds, cheese can be made.) Evaporate the solution until the sugar is deposited as a white, crystalline powder.

It is much less sweet than cane-sugar, but is easily digested. When milk is exposed to the air, the milk-sugar slowly changes into an organic acid called lactic acid, and this is the cause of the sour taste.

70. **Starch.**—Starch occurs in almost all plant life, and especially in seeds and tubers, those storehouses of food for the young seedlings. Starch is usually manufactured from potatoes, but also from wheat and rice.

EXPERIMENT 78.—(*a*) Place a little flour in a muslin bag, hold it in a basin containing a small quantity of water, and *knead* it thoroughly. Starch escapes through the meshes, and produces a milky appearance in the water. The minute starch granules are *not dissolved* but *suspended* in the water. **Starch is insoluble in cold water.**

(*b*) Pour a little of the starch water into a test-tube, and add one drop of **iodine solution. A blue colour** is produced. This blue colour forms an excellent **test for starch.**

(*c*) Pour another portion into a test-tube, and heat it until it boils. Filter. Test the filtrate with iodine. It turns blue, showing that starch will dissolve in boiling-water.

NOTES.—(i.) *Starch exists in plants as very tiny granules. When heated with water, these granules swell up and burst. The contents of the granules are soluble, though the skin is not.*

(ii.) *When* **starch paste** *is required for stiffening linen, etc., the starch is made into a thin paste with* **cold water,** *and then* **hot water** *is added until a jelly-like mass is produced.*

(iii.) *One of the chief reasons for cooking foods is to produce this change in the starch contained in them.*

EXPERIMENT 79.—Add a few drops of **dilute hydrochloric acid** to some starch in a porcelain dish, and heat gently. A sticky mass, called **dextrin** or **gum,** is obtained. Test its solubility.

Heat still more; some of it turns into **glucose** or **grape-sugar.** In the body this is caused by the action of the **saliva.** Starch cannot be used as food, but **saliva** turns **starch** into **glucose,** which can be digested.

NOTE.—*The change is brought about by a* **ferment** *in the saliva, called ptyalin.*

71. **Gluten and Albumen.**—We have stated that nitrogen enters into the composition of several organic bodies. Let us examine two such substances.

EXPERIMENT 80.—Knead the flour used in Experiment 78, until as much of the starch as possible has been driven through the meshes of the bag. The sticky mass which remains in the bag is called **gluten**, and is a valuable **food-stuff**. Dry a portion, and note the horny, brittle substance formed. Heat a portion with **lime** in a strong, glass **tube**. **Ammonia gas** can be detected in the fumes given off, showing that **nitrogen** must have been present.

EXPERIMENT 81.—Separate some white of egg, which contains **albumen**, from the yolk. The colourless liquid is soluble in water, but on heating, it **coagulates**, forming the white portion which is seen when eggs are boiled or poached.

Heat with lime, and prove that **nitrogen** is present by the escape of **ammonia** gas.

72. **Alcohol.**—This liquid has been known from the earliest of times, because it is contained in all **fermented juices** of fruits. There are several alcohols, but we shall only consider the one which is commonly called "**spirit of wine**," and which is found in wines, beers, and spirits.

When the juice of grapes is kept for a time it *ferments* —that is, it changes into *wine*. This is brought about by small *vegetable* organisms called **ferments**. These are present on the plants and fruit, and in the air, and during fermentation they feed on the juice, especially the **sugar** in it, and produce in its place **alcohol** and **carbon dioxide**.

Yeast is a ferment, which will be found suitable and interesting to study.

EXPERIMENT 82.—Make a warm solution of sugar in a flask, add some yeast, and keep in a *warm* place for two or three days. Note that a gas is steadily given off. Prove by fitting the flask with a delivery-tube dipping into lime-water in a test-tube that the gas is **carbon dioxide.**

Filter the contents of the flask, and distil the filtrate, taking care that the liquid never boils. A simple but suitable apparatus for carrying this out is shown in Fig. 83. A wet cloth should be placed on flask *B*, and

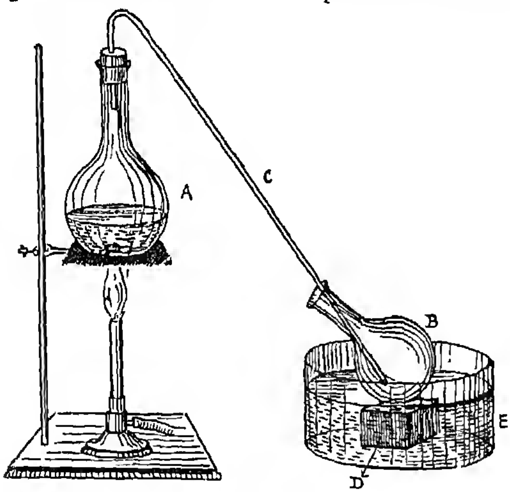


FIG. 83.

cold water poured on it at intervals to keep it as cool as possible.

Examine the liquid which collects in the receiving flask, noting its taste and smell. It is a mixture of **alcohol** and **water.** Pour some into a dish, and see if it will burn.

NOTE.—*If it fails to do so, gently distil the liquid again, taking care to keep the temperature well below the boiling-point of*

water. With each distillation more alcohol and less water should be carried over. Alcohol boils at 78° C.

Methylated spirit is a mixture of spirits of wine with 10 per cent. of another kind of impure alcohol—**wood spirit.** To the mixture a small quantity of paraffin oil is added to give it such an unpleasant taste that people will not drink it. This is a wise precaution, since **methylated spirit** is very largely used in many trades.

Compare the odours of the liquid collected in the last experiment and methylated spirit. Mix a small quantity of each with water. The **methylated spirit** shows a **milky** appearance, due to the impurities in the wood spirit.

Burn some methylated spirit—it gives a colourless flame, and leaves no residue.

Prove by weighing a known quantity of alcohol in a bottle that it is lighter than water.

NOTE.—100 *c.c. of water will weigh* 100 *grams.*
" " *pure alcohol will weigh* 79 *grams.*
Therefore the specific gravity of alcohol is ·79.

Alcohol is very valuable as a **solvent**, especially as it will **dissolve** many **bodies** that *water* cannot—for instance, **camphor, iodine** (used in first-aid dressings), **paraffin wax**, certain **gums**, and **resins**. The solution of the two latter in alcohol is the basis of spirit **varnish**

On the other hand, it has a hardening effect on food, flesh, and skin, and is largely used in museums as a liquid in which to preserve specimens.

NOTE.—*Beer contains from*	3 *to* 8	*per cent.*	*of alcohol.*
Wine " "	7 *to* 20	"	"
Whisky "	25 *to* 45	"	"

73. **Acetic Acid.**—When wines or beers turn sour, **vinegar** is produced. This is due to the action of another ferment upon the alcohol, causing it to absorb more **oxygen** from the air, and forming an organic acid—**acetic acid.**

Alcohol + oxygen = acetic acid + water.

Usually vinegar is made from cider (the fermented juice of apples) or wine, but certain vinegars are also made from **malt** and **sugar.** Ordinary vinegar contains about 6 per cent. of acetic acid. The acid character of vinegar can be easily tested by dipping a *blue* litmus paper into it.

Most boys know that ordinary pickling-cabbage is purple with a distinct tinge of blue, but that when *pickled* it is a bright red. This is due to the acetic acid in the vinegar used for the pickling.

SUMMARY OF CHAPTER XIX.

Organic Substances.

1. The chief elements found in animal and vegetable matter are—**hydrogen, oxygen, carbon,** and **nitrogen.**

Sugar.

2. Sugar is composed of **hydrogen, oxygen,** and **carbon.** In every sugar molecule the hydrogen atoms are twice as numerous as the oxygen atoms.

3. **Cane, grape,** and **milk sugars** are three of the most important kinds. The last often turns *sour* when exposed to the air, changing into **lactic acid.**

Starch.

4. Starch occurs in all plant life, but is chiefly obtained from **potatoes, wheat,** and **rice.**

5. The tiny grains of starch are enveloped in a skin which renders the starch **insoluble in cold water.** This skin bursts on heating, and the starch will then dissolve.

6. The addition of hydrochloric acid and heat changes starch into gum or dextrin.

7. The saliva of the mouth converts starch into sugar, rendering it digestible.

Gluten and Albumen.

8. These are important plant and animal substances containing nitrogen.

Alcohol.

9. Spirits of wine, or alcohol, is produced during fermentation.

10. Alcohol—

(*a*) Will burn.
(*b*) Is lighter than water.
(*c*) Is a valuable solvent.

11. When wines or beers turn sour, vinegar is produced The alcohol has been changed into acetic acid.

CHAPTER XX

SOAP

74. **Cleansing Substances.**—Knowing how much a housewife relies on soap for cleansing purposes, and how difficult we find it to wash without soap, we may well wonder how people managed before the way to make it was discovered.

Probably most of them used some form of *potash*, which we learned could be obtained from *wood ashes*.

Then, again, there was a mineral called "Fuller's earth," known from very ancient times as a cleansing agent.

But in the time of the Romans a kind of soap was known, made by treating grease with the potash from wood ashes. From the time it was introduced into this country until two hundred years ago, soap was mainly made *in the household* along with candles.

75. **Composition and Manufacture of Soap.**—EXPERIMENT 83.—Place some beef dripping in a large beaker, half-filled with rain-water. Add a strong solution of caustic soda, and gently warm, so that the liquid just simmers. After an hour or two, the layer of fat at the surface will have disappeared, a *scum* taking its place. The addition of common salt to the liquid will aid the rise of the scum.

Strain this scum into another beaker, add some warm water, and stir. A lather is produced. The scum is soap.

Soap is made by acting on oil or fat with an alkali. Fats and oils are compounds of organic acids and glycerine. When boiled with caustic soda, for example, the latter turns out the *glycerine* and unites with the acid itself forming a *soap*.

The chief fats used are—

Stearin, the chief constituent of mutton fat.
Palmitin, ,, ,, ,, palm oil.
Olein, ,, ,, ,, olive oil.

Stearin, for instance, is stearic acid united with glycerine. When treated with caustic soda, the glycerine separates out into solution and sodium stearate or soap is formed.

NOTES.—(i.) *Glycerine is a thick, colourless* syrup, *which mixes with water, and has a very sweet taste. It is largely used in medicines.*

(ii.) *If* caustic potash *is used instead of* caustic soda, "*soft*" *soap is obtained.*

(iii.) *In the* factory, *the melted fat or oil is poured into large* vats, *which are heated by steam-pipes passing through them. Only a sufficient quantity of caustic soda is added, as free soda in a tablet of soap is injurious to the skin. After this process is completed, common salt is added to the frothy solution, the soap curd rises to the top, it is drained off and allowed to cool, when it slowly solidifies.*

(iv.) *Soap powders, often known as "dry" soap, usually are a mixture of soap and ordinary washing-soda. Other soaps or "cleansers" which are used for cleaning paint, or scouring vessels, have fine sand or pumice mixed with them.*

EXPERIMENT 84.—Add hydrochloric acid to a strong soap solution. The soap is broken up, because the sodium attaches itself to the chlorine in the hydrochloric acid, to form sodium chloride (that is, common salt), while the stearic acid is now set free, and rises as a scum to the surface. Taste the water—it is salty. Collect

some of the scum, and allow it to dry. Heat a portion in a small crucible—it burns. Candles are now usually made of stearic acid instead of tallow as formerly.

EXPERIMENT 85.—Add some chloride of lime, (=calcium chloride) to a quantity of soap solution. A white scum forms. As in the last experiment, an interchange has taken place.

Sodium stearate + calcium chloride =
calcium stearate + sodium chloride.

Now calcium stearate may be called a lime soap, but it is insoluble in water. So is magnesium soap. That is the reason why water containing calcium and magnesium salts in solution is "hard" water. Part of the soap is used up in the formation of the lime and magnesium soaps before the rest of it can perform its cleansing operation.

SUMMARY OF CHAPTER XX.

Soap.

1. Soap is made by boiling oil or fat with an alkali.

2. Fats and oils are organic acids combined with glycerine. The alkalis unite with the organic acids to form soap, setting the glycerine free.

3. Caustic soda is used for the manufacture of most soaps. Caustic potash is used in making soft soap.

4. When lime is added to a soap solution it turns out the caustic soda, forming a lime soap which is insoluble in water. This is similar to the action of hard water on soap.

CHAPTER XXI

METALS

76. **How found.**—It is generally known that gold and silver are found at various places in the world in a more or less pure state, and that it would be possible for an ordinary person to detect them; but for the most part metals exist in the earth and rocks, in combination with other substances.

These **ores** (as the combinations are called) have to undergo certain processes, such as **smelting**, before the metals can be extracted.

Most of the heavy metals, such as copper, lead, and iron, are chiefly found as—

oxides	(metal + oxygen)
carbonates	(metal + carbon + oxygen)
sulphides	(metal + sulphur).

If these substances were found pure, the difficulty of extraction would not be great, but to add to the trouble, in most ores two or more metals are combined, few are free from impurities, such as **clay** and **sand**, and often it requires skilful management to obtain the pure metal.

The general process in dealing with ores is: **Carbonates** or **sulphides** are first **roasted** in a furnace supplied with an **air blast**. The **carbon dioxide** is driven off by the heat, while the sulphur combines with oxygen to form **sulphur dioxide**, which also escapes. In both cases an **oxide** is left.

To separate the metal from the oxygen in the **oxide**, the material is put into a **blast furnace**, mixed with **coke** or some other form of **carbon**, and intensely heated.

The carbon unites with the oxygen, and leaves the metal free; of course, the process is by no means quite as simple as indicated above. Each metallic ore has its own peculiarities, which require careful study to produce the best results. We will consider the extraction of **iron** as an example.

77. **Iron.**—Iron is only extracted from **oxides** and **carbonates**, the latter being the most important English ore. The first step is to **calcine** the ore (that is, **roast** it) in order to expel **water**, **carbon dioxide**, and the small quantities of **sulphur** and **arsenic** that are present.

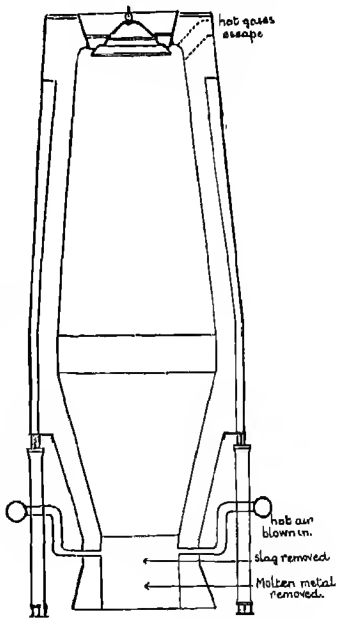


FIG. 84.

The second step is to **smelt** the ore in a **blast furnace**. This is a tall tower, from 70 to 90 feet high, usually shaped as shown in Fig. 84.

The mixture of iron **ore**, **limestone**, and **coke** is fed into the furnace at the top. Hot air is blown in through special openings near the bottom. Once the furnace is started working, it is not allowed to go out for very long periods. The changes that take place are not very simple, but finally the

carbon in the coke combines with the oxygen of the ore, and the metal itself in a molten state accumulates at the bottom of the furnace.

The limestone is changed by the heat into lime, and combines with most of the impurities to form a "slag," which floats on the top of the iron. From time to time the molten slag is drawn off by a convenient hole, and the molten iron by a lower hole to be run into sand moulds, where it cools and solidifies to form "pig-iron."

This pig-iron still contains many impurities which render it brittle. When it is re-melted and cast into moulds, it is cast-iron. Grates, stoves, and many other household articles are made of cast-iron.

Wrought-iron is obtained from cast-iron by burning out the greater part of the remaining impurities.

Steel contains about one per cent. of carbon. Usually it is produced from cast-iron by the Bessemer process, which consists of blowing hot air through molten iron contained in a pear-shaped vessel, called a "converter," until the impurities are nearly all burnt out, and then adding iron containing sufficient carbon to convert the whole mass into steel.

Some of the best steel is made by adding the right amount of carbon to wrought-iron.

Steel is often alloyed with small quantities of other metals, such as nickel and manganese. These affect the elasticity and hardness of the steel, thus rendering it suitable for certain special purposes.

78. **Aluminium.**—A few years ago aluminium was a rarity. To-day it is becoming of increasing importance in daily life. There are enormous quantities of aluminium in the earth; it forms an important constituent, not only of many well-known rocks, but also of clay,

which is so widely distributed. But the difficulties of extracting it were great and costly, until electricity solved the problem.

The substance from which the metal is extracted is alumina, the oxide of aluminium. This is first dissolved in a molten salt of aluminium called cryolite in a large iron vessel lined with carbon. Carbon rods also dip down into the liquid from a metal support (see Fig. 85).

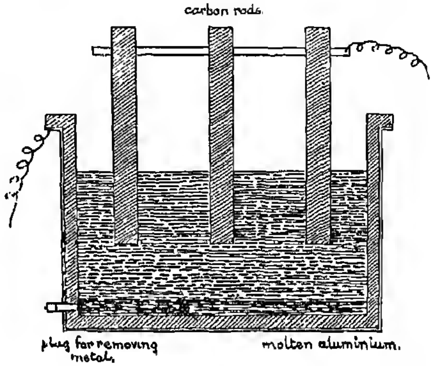


FIG. 85.

The carbon lining and the carbon rods form the *electrodes*, and are connected to the poles of a battery. An E.M.F. of about 6 volts is used, and, as the current passes from the carbon rods through the solution to the carbon lining, the alumina is broken up, oxygen being given off at the rods, and aluminium in a molten state collecting at the bottom, from whence it is periodically drawn off through the plug-hole shown in the diagram.

Aluminium is a very *light* metal (sp. gr. 2·6), and stronger than any of the common metals except iron and copper. It can be easily hammered into shape, drawn into wire, and can be cast in moulds. It is a good conductor of heat and electricity.

During recent years aluminium utensils have become very popular, their lightness, cleanliness, and durability being of great advantage to a housewife.

As aluminium is slightly affected by *alkalis* and certain

salts, any material or food containing either of these should not be allowed to remain for any length of time in vessels of that metal.

A mixture of *powdered* aluminium and iron oxide is known as **thermite** (or **thermit**). When ignited, it burns fiercely, producing a terrific heat, which is used in welding steel rails, mending broken propeller shafts, etc.

SUMMARY OF CHAPTER XXI.

Metals.

1. **Metals** are rarely found free, but combined as **carbonates, oxides, and sulphides.**

2. Smelting is usually carried out in two parts—

    (*a*) The ore is roasted to burn away as much as possible of the carbon dioxide, sulphur, and other impurities.

    (*b*) Mixing the roasted ore with carbon (usually as coke) and heating very strongly in a blast furnace.

3. Limestone is added to the materials in the blast furnace to combine with the impurities, forming a molten slag which can be run off.

4. **Wrought-iron** is purified **pig-iron. Steel** is made by adding a certain proportion of carbon to molten wrought-iron.

5. **Aluminium** is obtained **by electrolyzing** a molten oxide of the metal.

It is a very light metal, strong and easily worked, which renders it very useful for the manufacture of utensils and metal frames.

Section V.—APPLICATIONS OF ELECTRICITY

Chapter XXII

ELECTRICITY AND MOTION

79. **Movement of Needle and Armature.**—In Book II. we learnt that an **electric current** can—

(1) Cause a pivoted or suspended magnet to move (as in the current detector).

(2) *Pull* an iron armature (as in the Morse Sounder and the electric bell).

(3) *Magnetize* a piece of iron or steel.

Now we must ask ourselves: (i.) If a current can produce magnetism, *can magnetism produce a current?*

(ii.) If a current can cause the *movement* of a magnet, *can a magnet cause a wire carrying a current to move?*

Under certain conditions both of these are possible, and it is owing to discoveries in this direction that the **dynamo** and the **electric motor** have been invented.

We shall confine our attention at first to the production of *motion.*

Experiment 86.—Connect a rectangle of *stout* copper wire, by means of two lengths of very fine copper wire, to a battery or accumulator, and suspend, as shown in the diagram of Fig. 86. The use of the thin wire is to ensure that the rectangle is free to turn easily. When the rectangle is quite steady, bring one pole of a bar magnet near to one side.

Now, if you watch closely, you will notice a very slight movement of the rectangle—that the side to which the magnet is presented is deflected to the right or left. If the other pole is brought near the same side, you will find it is deflected in the opposite direction.

Unless you have a very strong current flowing through the wire and a powerful magnet, the effect will be so small that you would probably not notice it if you were

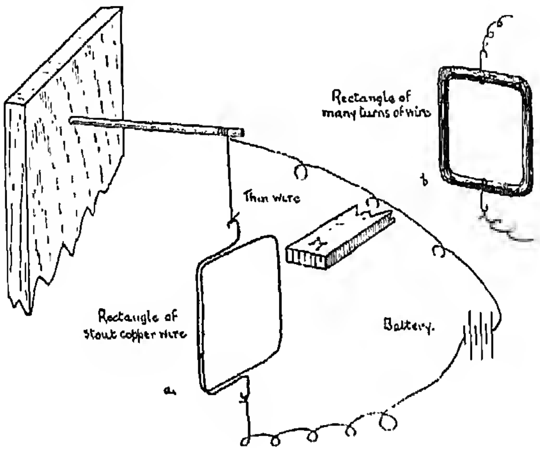


FIG. 86.

not looking for it; but it was the detection of such a motion that set scientists on the line of investigation that ultimately led to the invention of the electric motor.

The effect can be increased by using a coil of *many* turns instead of the square coil of one turn [see Fig. 86 (*b*)].

EXPERIMENT 87.—Bend one end of a stout piece of *bare* copper-wire, about 8″ long, into a loop, and bind a few strands of *very fine* bare copper-wire to the

other end to form a small brush. (Use fine copper-wire for binding; this will help to secure a good contact.)

Suspend the wire and brush from a *brass* hook, allowing the brush to rest *lightly* on a *brass* plate (see Fig. 87). Bring a horseshoe magnet so that the wire is

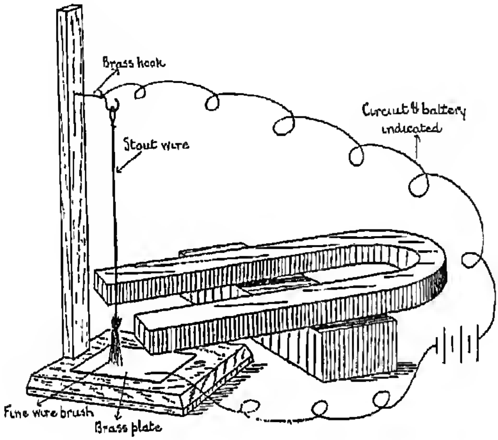


FIG. 87.

midway between the poles. Connect the brass plate to one pole of a *strong* battery, and the brass hook to the other pole. As soon as the circuit is completed, the upright wire through which the current is flowing will give a jerk. Notice the *direction* in which it moves; it is at right angles to the line joining the poles of the magnet.

It may, therefore, move either towards or away from the magnet. This depends on the direction of the current. On reversing the current (by changing the wires joining the poles of the battery) the upright wire will move in the *opposite* direction.

Again, the effect will be small unless a strong battery

is used, but since *it illustrates the principle of the electric motor* the experiment is worth carrying out.

Notice carefully that—

1. The direction of the current is vertical.

2. The direction of the lines of magnetic force is horizontal—*i.e.*, from pole to pole.

3. The direction of the motion is also horizontal, but at right angles to the lines of magnetic force.

The three directions are like the three edges forming one corner of a cube; each edge is at right angles to the other two edges.

When a wire carrying a current is placed at right angles to a magnetic field, it tries to move in a third direction at right angles to both.

NOTES.—(i.) *In the above experiment, if the brush is arranged so that it just touches the plate, as soon as the circuit is made, its movement lifts it from the plate. This breaks the circuit, and the brush falls back on the plate. The circuit is thus completed again, and another jerk of the wire takes place. The up-and-down motion may be continued for some time.*

(ii.) *If an accumulator is being used to supply the current, disconnect as soon as the wires show a tendency to overheat.*

80. **Moving-coil Galvanometer**—EXPERIMENT 88. —Place a rectangular coil of a great many turns of fine insulated copper-wire between the poles of a horseshoe magnet with parallel sides. (These may be often obtained "second-hand" for a few pence, as they are used in many forms of magnetos, but, failing a horseshoe magnet, two bar magnets can be placed parallel to each other at the right distance apart, the North ends lying in opposite directions and being firmly kept in position.) Suspend the coil as indicated in Fig. 88.

The bottom end is bare and allowed to rest on a brass plate.

Connections are made with a battery, as shown, and a current thus passed through the coil. Arrows in-

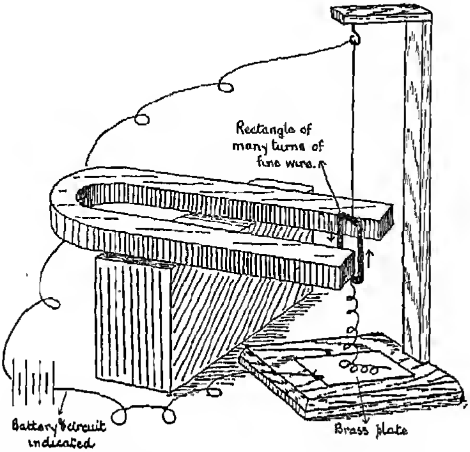


Fig. 88.

dicate the course of the current, and you will note that the *direction* of the current in *one* side of the coil is the *reverse* of that in the *other*.

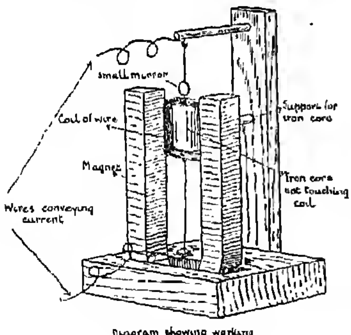


Diagram showing working of moving coil galvanometer

Fig. 89.

The sides will, therefore, be urged in opposite directions, thus causing the coil to rotate through a certain angle, which will depend upon the strength of the current. This rotation can, therefore, be used to measure the strength of the current.

A simple form of moving-coil galvanometer is shown in Fig. 89. The coil is wound as before, but inside of

it is a *fixed* short bar of soft iron, so that when the coil moves it rotates round the iron bar. The use of the bar is to concentrate the magnetism as much as possible in a straight line between the poles. A pointer can be attached to the coil, with a circular scale under it, but a small mirror is often used, as shown in the diagram. A beam of light is thrown on the mirror from a lamp, and the rotation is measured by the movement of the *reflected* beam.

We shall see in the next chapter how these principles are applied in the construction of the electric motor.

SUMMARY OF CHAPTER XXII.

1. If a copper wire is placed between the poles of a horseshoe magnet at right angles to the line joining the poles and a current passed through the wire, it will tend to *move*.

2. The direction of movement will be such that it is at right angles both to the line of the wire and the lines of magnetic force between the poles of the magnet.

3. If a current is sent through a coil placed between the poles of a horseshoe magnet, the coil will tend to *rotate*.

This is the principle of both the moving-coil galvanometer and the electric motor.

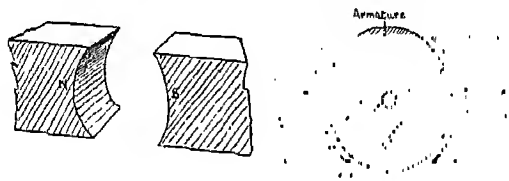
Chapter XXIII

THE ELECTRIC MOTOR

81. **The Parts of a Motor.**—The electric motor consists of *four* main parts: (*a*) the field magnet; (*b*) the armature; (*c*) the commutator; (*d*) the brushes.

From the description given in this chapter, these parts should be easily detected on any simple model and their use understood. The making of a simple form should not then prove difficult.

82. **The Field Magnet.**—The use of a field magnet in a motor is to set up a strong magnetic field in which the armature (*i.e.*, a revolving coil) can rotate freely. For this purpose, an arrangement, based on the diagram of Fig. 90 (*a*), is very suitable, in which two magnetic



a b

Fig. 90.

poles face one another, with a cylindrical space between them to contain the armature.

Note.—*To utilize the magnetic force to its fullest extent, the gap between the armature and the poles should be as small as possible* [*see Fig.* 90 (*b*)].

The magnet can be a permanent magnet, but in most cases it is an electro-magnet. Electro-magnets are

constructed in many different designs, a few of which are shown below. The construction of the forms (*d*) and (*e*) is given in Chapter XXX.

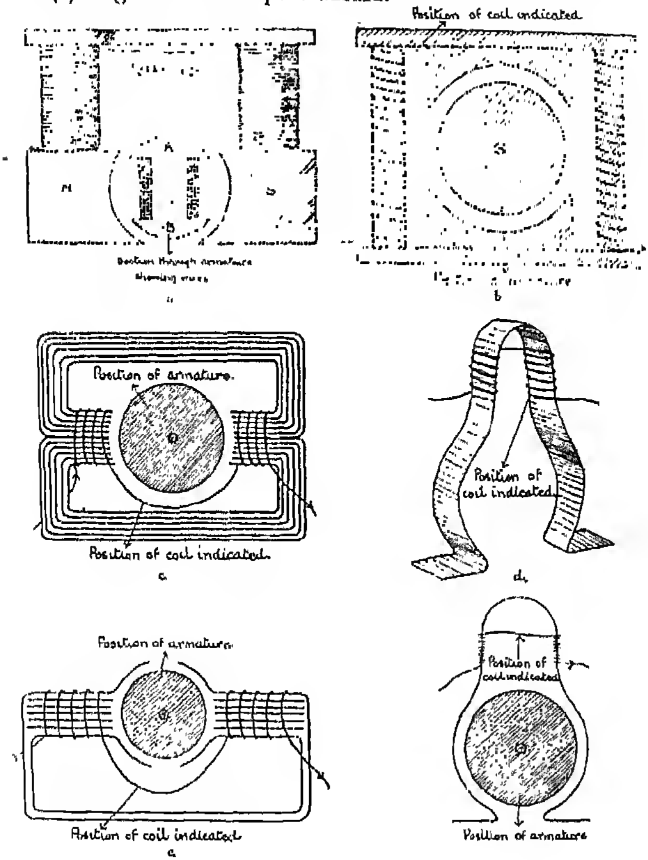


FIG. 91.

83. **The Armature.**—Just as there are different types of field magnets, so the **armature**, or moving coil of a **motor**, may be any one of four distinct varieties. To

understand its work we will take as an example the H armature (or Siemen's), one of the simplest and earliest kinds.

A typical pattern is illustrated in Fig. 92. A soft iron cylinder, with two grooves cut lengthwise, is wound, as

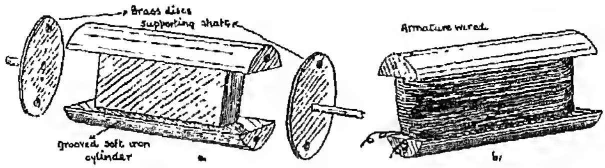


FIG. 92.

shown, with insulated copper wire. The two pieces of shaft are screwed into the centre of two brass discs, which are then screwed to the cylinder (by means of drilled holes). The armature, when mounted, appears as shown in Fig. 93.

Examine the section given in Fig. 91 (*a*), where the armature is shown mounted between two poles of a magnet. Lines of magnetic force pass from the north pole to the south pole. If a current traverses the wire of the armature, it will do so at right angles to the direction of the magnetic force, and from what we discovered in Paragraph 79 we know that the armature will tend to rotate. Or we may consider the problem in another way. The current through the wire causes the armature to become an electro-magnet. Suppose that the direction of the current is such that *A* becomes a *north* pole and *B* a *south* pole. Then we see that *A* will be attracted towards *S* and *B* towards *N*. The movement will carry the armature slightly past those positions; *but unless some change is made in the arrangement,* the armature will come to rest in the position in which unlike poles are opposite each other.

But if, as soon as *A* slightly passes *S* in its downward motion, the current is reversed, *A* will become a south pole. It will, therefore, be repelled from *S* and urged toward *N*. *B* will similarly be drawn towards *S*.

Again, their speed would carry *A* and *B* slightly past the poles to which they were drawn. They would not get far beyond; but *by reversing the current again*, on they would travel.

It will be seen that a continuous turning can be obtained, if the current is reversed *at each half revolution of the armature. How can this be done?*

The commutator is the part of the motor by which the current is reversed at the right moment.

84. **The Commutator.**—This is a split ring of copper or brass (*i.e.*, a ring divided into two semicircular

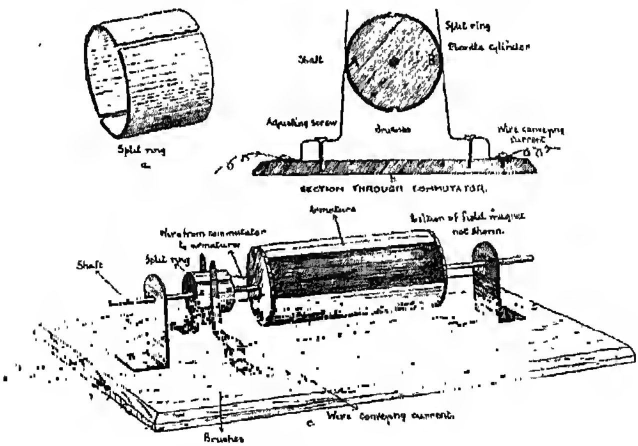


Fig. 93.

parts), mounted on a small cylinder of ebonite, or of hard wood, which fits tightly on the shaft and revolves with it. The diagram in Fig. 93 shows the arrange-

ment of the parts. Care must be taken that the two halves *do not touch.* Each of them is attached to an end of the armature wire.

Against the split ring rest the **brushes.** In small models these are usually two brass strips, which serve to convey the current. In the diagram of Fig. 93 *b*, the current is shown entering from the left and leaving at the right.

When the section of the ring marked *A* is at the left, the current goes through the wire of the armature in the direction from *A* to *B*; but when the shaft has turned through half a revolution, *B* will be at the left, and the current will traverse the armature from *B* to *A*.

85. **Connections.**—If a permanent magnet is used as the field magnet, the wires from the battery are connected *direct to the brushes;* but if an electro-magnet is used, then the connections are as follows:

One pole of the battery is joined to a terminal of the field magnet, the other pole to a brush. The remaining brush is connected to the second terminal of the field magnet.

This puts the armature and field magnet in **series** with the battery. Thus the current goes from the battery through the field magnet, then through the armature by means of the brushes, and back to the battery.

86. **Construction of a Motor.**—It will be seen that there are certain difficulties in obtaining the necessary iron cylinder and in drilling the holes for the model just described, but a very simple adaptation of the model (see Fig. 94A), in which ordinary "tin" is used for the armature, is given in Chapter XXX. This should prove quite simple to construct, and will work well with a 4-volt

dry battery. It is, however, not quite as efficient nor as compact as the tripolar motor, which has also been included (see Fig. 94B). The latter is not much more difficult to construct, but requires greater care in connecting the armature wires to the commutator, and it is not so easy for a boy to understand from it the principles which underlie the working of a motor.

Attention should be concentrated on the purpose of each part rather than on the exact copying of any given

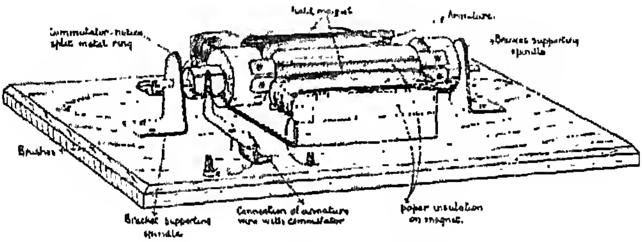


FIG. 94A.

model. When the use of each part is grasped, many adaptations from the pattern may be attempted so that available material can be used.

87. **Remedying Defects.**—Having made a motor, a boy often feels disappointed because at first it will not work. Usually, however, the cause is some slight defect, and attention should be directed to—

1. The brushes. These should be just *lightly* touching the commutator, and the regulating screws should be turned until a correct adjustment is obtained.

2. The field magnet. Be careful to ensure that the wires cross from one pole to another in the correct manner. Note the directions given in Book II., Chapter X., on Electro-Magnets.

3. Insulation. See that bare ends of wires are not causing a short circuit anywhere, and see that all connections are securely made.

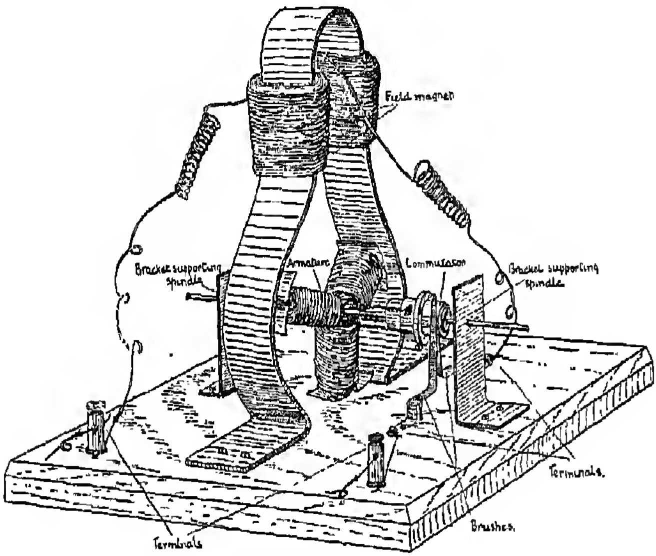


FIG. 94B.

NOTE.—*A tripolar motor is usually* self-starting—*that is, it works as soon as the current is applied. The two-pole armature, as a rule, is* not *self-starting; it is necessary, after connecting up with the battery, to give the armature a quick turn with the hand in order to start it. If turning it in one direction does not start it, try the other direction. The movement need not be at all violent, a half-turn being usually enough to set the motor at work.*

CHAPTER XXIV

THE DYNAMO

88. **Induced Currents.**—We have seen how the motion of a conductor (*e.g.*, the armature of a motor) can be brought about by means of a current acting in a magnetic field—in this chapter we shall study how, by the motion of a conductor (*e.g.*, an armature) in a magnetic field, a current can be produced.

EXPERIMENT 89.—Make a coil of a *large* number of turns of insulated copper wire, and bind together in any suitable way to preserve its shape. Connect the two ends of the coil to a sensitive galvanometer.

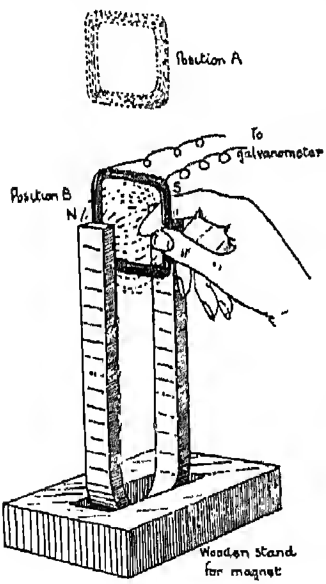


FIG. 95.

Set up a horseshoe magnet in a vertical position, as shown in the diagram.

Now move the coil *quickly* from position *A* (shown in dotted lines) to position *B*. Note that the galvanometer needle is *slightly* deflected, but that *as soon as the motion is stopped* it returns to the zero mark.

Next move the coil quickly away from the magnet. Again the needle is deflected, *but in the opposite direction.*

In these two cases a current has been produced *without using a cell.* Such a current is called an **induced current.** Notice that in position *B* more of the magnetic lines of force pass through the coil than in any other position. (Compare position *A*.) It has been found that a current is produced **whenever a change takes place in the amount of magnetic flux** (= magnetic lines of force) **passing through a circuit.**

If, then, the coil were continuously and rapidly moved up and down from *A* to *B*, little currents of elec-

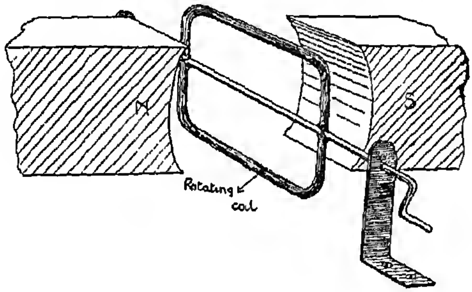


FIG. 96.

tricity would be produced in the coil, first in one direction and then in the other. These little currents would form what is known as an **alternating current.**

Instead of an up-and-down motion of the coil, it can be *rotated* between the poles of the magnet to produce a similar effect. In such an arrangement, for instance, as shown in Fig. 96, where the coil has been mounted on a horizontal axle, it will be seen that the *magnetic flux* through the coil *changes* as the coil passes from the *vertical* to the *horizontal* position and *vice-versa.*

NOTE.—*The greatest change takes place when the sides of the coil cut through the greatest number of magnetic lines of force—that is, when the sides are moving past the poles.*

If the ends of the coil are joined together, and the coil revolved as rapidly as possible, an alternating current will surge through the coil. How to collect such a current will be discussed in the next paragraph.

NOTE.—*The more rapid the motion, the greater will be the electro-motive force produced.*

89. **A Dynamo.**—You have already had an instance of a coil revolving between the poles of a magnet in your electric motor.

In the motor we sent a current through the coil of an armature placed between magnetic poles, and the armature revolved.

Suppose, however, the battery having been removed, and the ends of the wires joined together, the armature is revolved by some other means (*e.g.*, by a steam-engine), then *a current will be generated* in the armature coil. It will be an alternating current in the coil, but by the use of the split-ring commutator it can be collected as a direct current—that is, a current flowing in one direction.

When such a machine is used to produce a current, it is called a dynamo.

An electric motor and a dynamo are, therefore, *reversible*, electricity being supplied to the motor to produce *motion*, and motion being supplied to the dynamo to produce *electricity*.

For many purposes a *direct* current is the most useful, but in some cases it is desired to allow the current produced in the armature to travel through the whole external circuit as an alternating one. For this, a different arrangement of brushes will be needed.

Examine Fig. 97, which gives a diagram of one of the simplest methods. The ends of the wires

from the armatures are brought to the two metal rings *A* and *B* mounted on cylinders of some insulating material such as ebonite.

Note that the rings *do not touch*, and that although

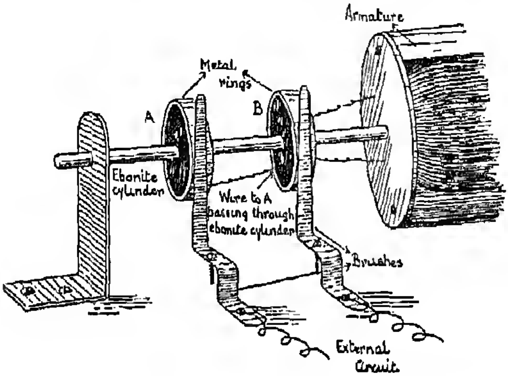


FIG. 97.

the wire in order to reach *A* has to pass through the core of *B*, *it is well insulated from it.*

Two metal or carbon brushes are kept in close, but light, contact with the metal rings, and are joined also to the ends of the wires leading to the external circuit.

The current will now pass into the external circuit in exactly the same form as it is produced in the armature.

NOTE.—*A* magneto, *in its simplest form, is a small dynamo in which an armature is caused to revolve at a high speed between the poles of a* permanent *magnet. The mixture of petrol vapour and air in the cylinders of a motor-car is ignited by the spark produced by a magneto.*

CHAPTER XXV

THE TELEPHONE

90. **Electrical Impulses.**—Before studying the construction of the telephone, two important points must be understood—

(i.) That if the magnetic flux through a coil of wire is suddenly increased or decreased, a momentary current of electricity flows through the wire.

(ii.) That the movement of a piece of soft iron near the poles of a magnet alters the distribution of the lines of force due to the magnet, causing them to become intensified in the neighbourhood of the soft iron. This change will result in an alteration in the flux through any coil which surrounds or is near the magnet, and therefore induce a current in the coil.

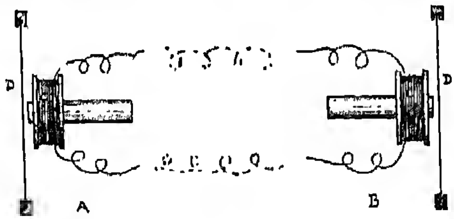


FIG. 98.

The first part has been considered in Chapter XXIV., but you should test (ii.) by placing a piece of cardboard over the poles of a horseshoe magnet and dusting iron filings over the cardboard. On tapping gently, the distribution of the magnetic lines of force can be seen by the arrangement of the filings. These will be altered if a piece of iron is brought near.

These principles were made use of by **Graham Bell** in constructing the **telephone** in 1876.

In Fig. 98, A represents a coil (C) of many turns of fine *insulated* wire, wound round a permanent bar magnet. In front of it is fixed a thin iron disc (D). If this disc is set in vibration—*e.g.*, by tapping it—slight changes will take place in the distribution of the magnetic field, increasing the number of lines threading through the coil as the disc approaches, diminishing them as the disc recedes. Very small currents will accordingly be set up in the coil of wire, *rapidly changing in direction with each vibration of the disc.*

If this apparatus is connected with a similar one (B), the current generated in the first will traverse the coil of the second, *and, according to its direction,* **strengthen or weaken the magnetic force of the second magnet.** This will cause the second disc to be alternately drawn towards or released from the second magnet, and *at exactly the same rate as the first disc vibrates.*

Thus one set of vibrations at A can be faithfully reproduced (though less in strength) at B. Such vibrations may be set up by a person speaking near one disc and heard by a person by means of the vibration of the other disc.

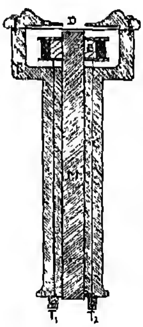


FIG. 99

Fig. 99 shows a section of the telephone as invented by Bell. The disc (D) is held firmly in its place by the mouthpiece (E), which is screwed to the case (C), in which bar magnet (M) is fitted. At the end of (M) can be seen the bobbin (B) of fine silk-covered wire. The ends of this wire are secured to two terminals T_1 and T_2.

91. **Construction of Telephone.**—To make a really good telephone requires a considerable amount

of skill and accuracy, but every boy should attempt to make a simple model. If reasonable care is taken, the results will give considerable pleasure, and at the same time teach more thoroughly the principle of the instrument than the mere examination of a telephone.

Fig. 100 shows two examples of receivers made from very simple materials. In both, the wooden cover of a

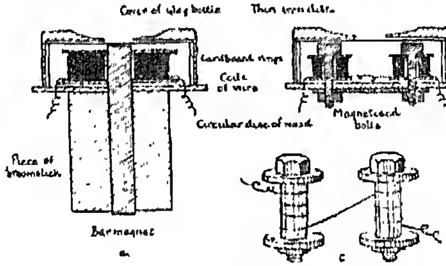


FIG. 100.

gloy bottle has been shaped for a mouthpiece, and a circular wooden disc cut out for a base. Inside the mouthpiece a ring of cardboard is glued, a disc of thin iron placed next to it, and another ring of cardboard glued round the sides to keep the discs firmly in position.

For the iron disc, you can buy a sheet of ferrotype iron from any photographic dealer very cheaply, and this will make a great many discs.

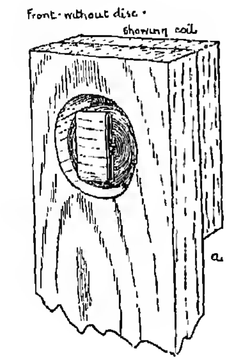
In (*a*) the round magnet is made to fit tightly in a hole drilled in a piece of broomstick to which the wooden disc has been glued. A bobbin of very fine insulated copper wire is placed around the top of the magnet, and the magnet is pushed up to such a height above the wooden disc, that when the mouthpiece is placed on it, the magnet *very nearly* touches the iron disc. The mouthpiece is then secured in position with glue.

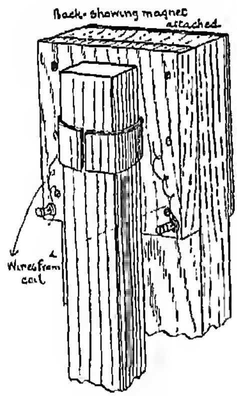
In (*b*) two small steel bolts are used for the magnets,

and magnetized as strongly as possible by means of a solenoid. A piece of soft iron acts as a keeper. The figure shows the arrangement, but care should be exercised to ensure—

(i.) That the heads of the bolts are of opposite polarity.

(ii.) That the wires are thoroughly insulated. It is a good plan to soak the bobbins after they are wound in melted paraffin wax. The bobbins can be easily constructed of cardboard and stiff paper.





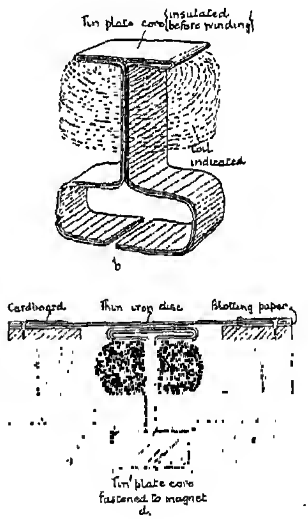


FIG. 101.

(iii.) That the wire goes round the bobbins in reverse directions [see Fig. 100 (c)].

The ends of the wires can be led through tiny holes in the wooden disc, and attached to any suitable terminals.

To test that it is in working order, touch the terminals with the wires from a battery. When the circuit is thus made through the telephone coils, a click will be heard from the instrument.

A very easily constructed and effective receiver, making use of an ordinary bar magnet, is shown in Fig. 101, and its construction given in Chapter XXX.

92. **Transmitter and Receiver.**—You will have noticed that no battery was mentioned in describing Graham Bell's method of sending messages by means of telephones. This would be an ideal method, but for the fact that the induced currents set up by the vibration of the disc are very feeble and would not be of any practical use for long distances. The Bell instrument is an excellent **receiver**, but not a good **transmitter**, and the standard receiver of to-day is very similar to the instrument as it was first invented, with the exception that, *for convenience*, the "watch-type" receiver, with its horseshoe magnet, is often used instead of the old form, with the long bar magnet.

For the purpose of *transmitting* speech, another kind of instrument altogether has been invented.

NOTE.—*A good plan for studying the telephone is to examine the standard transmitter and receiver thoroughly, and then to use the "home-made" receiver with the standard transmitter. If the receiver has been carefully made, although speech may be very blurred, yet the sound of a whistle through the transmitter should be plainly heard in the receiver. Later, when the forms of transmitter have been studied, the "home-made" model should be used in conjunction with a standard receiver.*

93. **The Microphone**—EXPERIMENT 90.—Screw two dresser hooks about 2″ apart into the bottom of a thin wooden box (a cigar-box is very suitable), and lay a thin metal rod (*e.g.*, a portion of a knitting needle)

across the hooks, as shown in Fig. 102. Connect the hooks in series with a battery and a good telephone receiver. Place the receiver at your ear and gently scratch the sides of the box.

The sound is heard quite plainly in the telephone

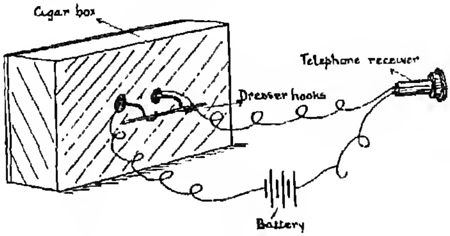


FIG. 102.

receiver. If a sharp tap is made on the box, the effect, as heard in the telephone receiver, is quite powerful.

Trace the course of the current from the battery to one of the hooks, thence by the rod to the other hook, from which it travels to the receiver and back to the battery.

Where the rod rests lightly on the hooks, the current finds a considerable resistance, *which increases or diminishes as the rod shakes.* When the rod is pressed tightly on the hooks, the current can flow more easily than when the contact is very loose.

Every variation in the resistance in the circuit gives rise to a variation in the flow of the current, and therefore affects the receiver.

The ticking of a watch placed on the top of the box will cause the rod to vibrate with it, and thus give rise to a similar sound in the receiver. The effect varies considerably with the kind of box used. If the wood of the box is thin and resonant the ticking will be almost as audible when the receiver is placed near the ear as if the watch itself were placed there.

NOTE.—*The rod and hooks constitute the simplest form of* microphone—*that is, an instrument for transmitting minute sounds.*

Since carbon is used in most forms of microphone, each of the following simple pieces of apparatus should be set up and tried—

(*a*) Fig. 103 shows two short lengths of carbon, *A A* (*e.g.*, pieces of carbon rod used for arc-lights), mounted on the bottom of a cigar box. A thinner piece of carbon rod about $1\frac{1}{2}''$ long and tapered at each end rests lightly in conical hollows in the sides of the carbon uprights. Connecting wires are *firmly* attached to the latter by binding them *tightly* in a groove filed round the rods near the base. These wires lead to a battery and receiver, as shown.

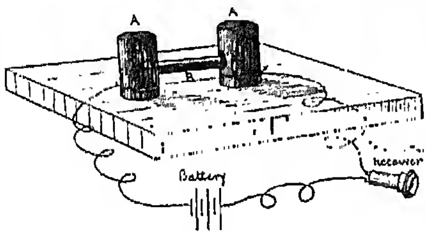


FIG. 103.

Similar but much more reliable effects can be obtained from this microphone than from the hooks and rod mentioned in the previous experiment.

If no other carbon rods are available, the graphite (a form of carbon) of lead pencils can be used with success. Fig. 104 shows two uprights of carpenter's pencil, which have been bared to expose the graphite core. In this two hollows have been made, and a piece of ordinary soft lead pencil, sharpened at both ends, used as a connecting rod.

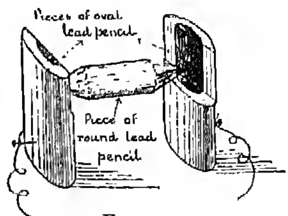


FIG. 104.

NOTES.—(i.) *In setting up the above microphones, it is advisable to glue one upright and let it set before fixing the rest.*

(ii.) *A brass pin driven into the graphite near the base will be suitable for fastening the wires.*

(iii.) *The middle rod should be able to move quite freely.*

(*b*) An improvement on the above apparatus can be effected by increasing the number of carbon contacts. A plan of a simple arrangement is given in Fig. 105.

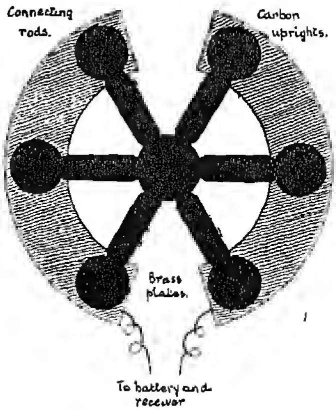


FIG. 105.

The carbon uprights rest on two pieces of brass, so that the current passes from one group of three carbon rods to the centre, and thence to the other group of three. Any vibration of the connecting rods will affect the receiver. By using the vibrations of a greater number of rods, the effect is not only strengthened and made more sensitive, but the instrument will work even if one of the rods "sticks."

EXPERIMENT 91.—A still greater number of carbon contacts can be obtained by the use of carbon granules, and that is the principle used in most modern transmitters. To understand how this works, construct the apparatus shown in Fig. 106. Details of construction are given in Chapter XXX.

On referring to the diagram you will note that the essential parts are a metal plate at the back, a disc of ferrotype in front, and a number of carbon granules enclosed in the space between them. The face of the

ferrotype disc touching the granules is freed from varnish, so that, on connecting the two discs to the poles of a battery, a current will flow, which will pass through the carbon granules.

A receiver should be included in the circuit, as indicated in the figure.

The carbon granules, like the rest of the circuit, offer a certain amount of resistance to the passage of the

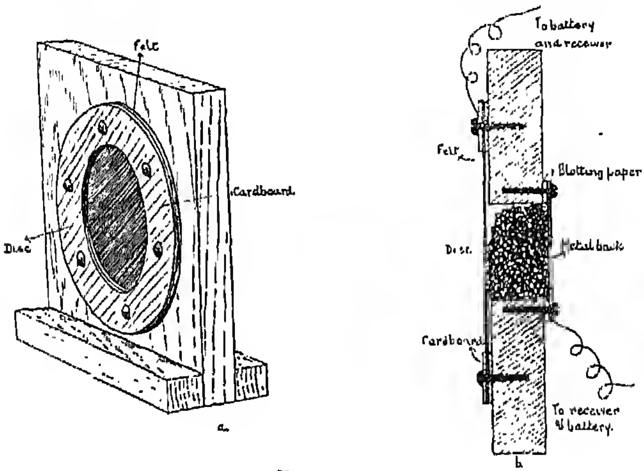


FIG 106.

current. But this resistance becomes *less* when the granules are more tightly packed and *greater* when they are held more loosely. This happens *whenever the ferrotype disc vibrates.* Every tiny vibration causes a slight variation in the strength of the current in the circuit, and, although these variations may take place hundreds of times in a second, yet they will affect the magnetic force in the receiver and cause the disc of the receiver to vibrate in exactly the same way as that of the transmitter. Suppose that these vibrations were first set up

by someone speaking in front of the transmitter; every tone of the voice would make the disc vibrate at a rate which depends on the *pitch* of the tone. These vibrations would be faithfully reproduced by the disc of the receiver, which, in its turn, would throw the air around it into corresponding vibrations. These would affect the ears of anyone listening, and so the listener would hear similar sounds to those produced by the voice at the transmitter, although that might be miles away.

NOTES.—(i.) *When a microphone is used as a transmitter, a battery* must *be included in the circuit.*

(ii.) *Carbon granules can be obtained by pounding pieces of arc-light carbon rod into as fine a state as possible, or using tiny fragments of the* graphite *from lead pencils. Finely-ground coke will also give a good effect.*

(iii.) *Care must be taken that the screws fastening the two discs to the wood are not in contact with each other, else the current would prefer to pass mainly through them, rather than through the granules.*

(iv.) *Good contact must be ensured between the battery wires, the screws, and the discs to which they are attached, and all connections must be firmly made. Loose wiring causes a jarring sound in the receiver.*

(v.) *A ring of felt or similar soft material should be placed between the wood and the ferrotype disc. This damps any excessive vibrations.*

It must not be expected that your "home-made" apparatus will be equal to those used in the telephone exchanges. But, provided reasonable care has been used in making the transmitter, connecting with a battery and with a receiver in a distant room, whistling, or even speaking, before the transmitter should be plainly heard by anyone using the receiver. Words, however, are likely to be transmitted unequally; some will be very distinct, while others will sound blurred.

In one form of commercial transmitter the disc (or diaphragm, as it is often called) is of thin carbon, and is prevented from injury by a protective piece of fine copper gauze placed in front of it. The carbon block is insulated from the carbon disc by a ring of flannel or cotton wool. The face of this block is also *serrated*, so that as much contact surface as possible in a small space is obtained (see Fig. 107).

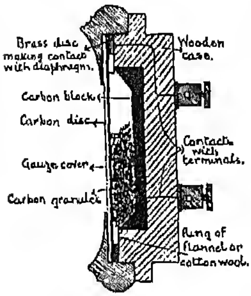


FIG. 107.

All the forms of transmitter employing carbon granules must be placed upright when in use, so that the granules will be in contact with *both* the front and back discs or buttons. Sometimes the granules settle into a compact mass at the bottom, and lessen the efficiency of the instrument. This can be remedied by turning the transmitter on its side or inverting it.

94. **A Telephone Installation.**—The making and setting up of a complete telephone installation, so that messages can be sent to and received from a distant station, is beyond the scope of this book. From an examination of such an installation, you will observe that each station, besides the transmitter and receiver, has an electric bell attached to it by which one operator can be "rung up" by the distant one. The wiring is so arranged that no current flows except when the instrument is being used.

The procedure for an installation, such as is often fitted in business houses for calling from one department to another, is as follows: The person wishing to send a message takes the receiver off the hook, and then

presses the push-button. This rings the bell at the distant station. The operator there may acknowledge the call by pressing his button, or be ready to receive the message by simply lifting off his receiver. When both receivers are off their hooks, the *bell* circuit is cut out and the telephone circuit completed. To prevent wastage of current, the receivers should be placed on the hooks directly the conversation is finished.

NOTE.—(i.) *The hook for the receiver is arranged as a lever, with a spring attachment. The receiver presses it down, and this completes an arrangement by which the bell can be rung by the distant operator. The lifting of the receiver causes the hook to spring up, cutting-out the "home" bell, and bringing in the "home" telephone.*

(ii.) *In some installations, the lifting of the receiver automatically rings the distant bell.*

CHAPTER XXVI

ELECTRIC LIGHTING

95. **Incandescent Lamps.** — When it was discovered that strong currents of electricity could raise the temperature of thin wires to a "white-heat," many attempts were made by inventors to use the light so produced in an electric lamp.

A wire was needed—

(*a*) Which would not melt when it became "white-hot"—that is, it must possess a high melting-point.

(*b*) Which possesses a fairly high resistance. (Heating of the wire by a given current depends on the resistance. To obtain the necessary resistance in a *good* conductor, the wire would have to be very long and thin.)

Platinum wire was used at first. It melts at 1750° C., does not rust in air, and, unlike most metals, it can be easily sealed into glass. But the light is feeble unless a strong current is used, and then the wire is very liable to melt.

96. **Carbon Filaments.**—From your study of a candle-flame, you learnt that its chief light is given out by myriads of incandescent carbon particles, those that are raised to a *white heat*, but which are unable to burn until they pass out into the region where there is sufficient oxygen.

Similarly, if a sufficient current of electricity is passed through a carbon thread or filament *in a space devoid of*

air, the particles will be heated to incandescence and emit light without being burnt away.

The inventors, therefore, turned their attention to **carbon filaments** for their lamps, for these would not melt, *whatever the temperature to which they were raised.* Many substances containing carbon were tried. Edison used *bamboo fibres* with great success, but *cotton-wool* is also largely employed. But whatever material is used, it must be **carbonized**—that is, heated out of contact with air—in order to drive off the volatile constituents and obtain the black carbon which is left behind. This process can be readily understood by remembering that *wood* becomes *charcoal* by being similarly heated.

If cotton-wool is chosen, the fibres are first broken up by treatment with **zinc chloride solution**, and the paste thus formed is pressed through fine holes in a metal plate. The filaments which come through are hardened in alcohol, wound to the required form, and then carbonized. By a special process, the filaments are next made of equal thickness throughout.

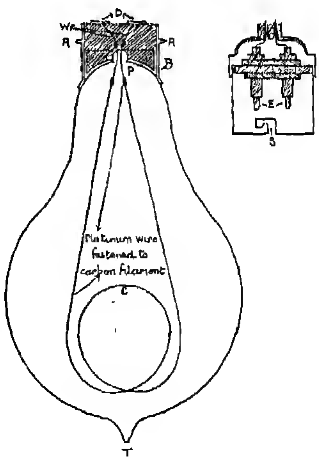


FIG. 108.

To understand the arrangement of the various parts of a carbon filament lamp, you should examine one, and compare it with the diagram given in Fig. 108.

The carbon filament (*C*) is attached at both ends to short pieces of platinum wire (*P*), which are connected

by means of copper wire (*W*) to metallic discs (*D*) in the brass cap (*B*). The latter is filled with an insulating cement, which holds the cap firmly to the glass bulbs.

The bulb at first terminates in a tube of glass (*T*) which remains open until all the parts are fixed. Then, by means of air-pumps, the air is as completely extracted from the bulb as possible and the bulb sealed off.

Next, note the method by which the lamp is held in the lamp-holder. In nearly every case, you will find the *bayonet* pattern is used. To place the lamp in position, the two projections (*R*) on the brass cap (see Fig. 108) must be fitted into the side slots (*S*) in the holder, then pressed gently, but firmly, and the lamp given a slight turn. This secures the lamp effectively in such a way that the two discs (*D*) on the cap are held firmly against two brass contact pieces (*E*) in the holder, to which the current is conveyed from the mains.

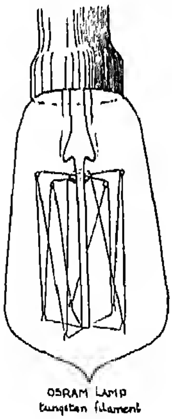


FIG 109.

97. **Metallic Filaments.**—Of recent years, owing to the discoveries which have been made of the very valuable properties of some of the rarer metals, carbon filaments have been very largely superseded by metallic filaments.

The metals chiefly used are **osmium**, **tantalum**, and **tungsten**. They have higher melting-points than platinum, and can be drawn into very fine wire.

A long length of wire is needed, and special methods have to be adopted for enclosing it in the bulb. One method is indicated in Fig. 109, but others can be seen in the various lamps now on the market.

The light produced by these metallic filaments is whiter than that produced by carbon, and requires less consumption of electrical energy to produce the same candle-power.

98. **Arc-Lamps.**—For the lighting of large spaces, such as streets and extensive shop frontages, arc-lamps are frequently used.

In most of these lamps, two carbon rods are placed with their pointed ends just touching as in Fig. 110 (*a*) and (*b*). The other ends of the rods are connected to the electric mains, and for the larger lamps a current of from 5 to 10 ampères at an E.M.F. of about 50 volts is passed through the circuit.

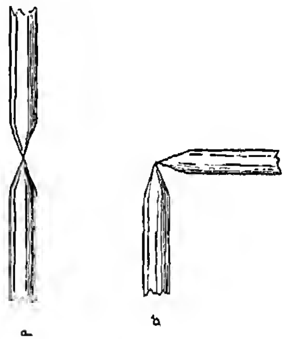


FIG. 110.

The rods are then gradually separated for a short distance, but the *current continues to pass across* from one to the other, and in the intervening space an intense white light is produced called the electric arc.

The carbons are gradually consumed, and one of the rods is attached to a *regulating* mechanism, which has two duties to perform—

(1) To bring the carbons in contact when the current is not passing.

(2) To keep the points at the right distance apart while the light is being produced.

99. **Efficiency of Lamps.**—It has been mentioned that electric lamps differ in efficiency—that one lamp, for instance, may consume considerably more electrical

energy than another in producing light of the same candle-power.

To be able to measure efficiency we shall need a unit, which will take into account both the electro-motive force and the current in the circuit.

When the E.M.F. is one **volt** and the current one **ampère**, the power in the circuit is called a **watt**.

Note.—*When the E.M.F. is* 20 *volts and the current* 5 *ampères, the power in the circuit is* 100 *watts.*

When the E.M.F. is 50 *volts and the current* 2 *ampères, the power is also* 100 *watts.*

Although a tungsten lamp may be more expensive to buy than a carbon filament lamp, yet it may be really cheaper in the end, for the consumption of electrical energy of the first is less than 1·25 watts *per candle-power* compared with about 4 watts per candle-power of the other.

With a large arc-lamp, the efficiency is much greater, for a brilliant arc of 900 candle-power requires 750 watts—that is, about ·8 watts per candle-power.

When electricity is supplied to a house from the mains, a **meter** registers the amount of electrical energy used either for lighting or driving motors in **watt-hours**. A motor driven by a current of 4 ampères and with an E.M.F. of 20 volts for 1 hour uses 80 watt-hours of energy.

Usually the kilowatt-hour, which is 1,000 watt-hours, is the unit employed.

99a. **Gas-Filled Lamps.**—Much progress has been made during recent years in the application of electricity to household needs, especially in the production of electric lamps. Carbon filaments are no longer used, and the tungsten filament, instead of acting in a vacuum, is now usually placed in a bulb containing an **inert** gas

such as nitrogen or argon, in which the tungsten filament will not burn. In a vacuum lamp, if a very high temperature is used in order to obtain a brighter light, the filament begins to volatilise—that is, to change into vapour. This shortens its life and blackens the bulb. With a gas-filled lamp, we can use a higher temperature and obtain a much brighter light without this happening, and also for a less expenditure of watts per candle-power.

But owing to convection currents set up by the hot wire in the gas in the bulb, it has been found advisable not to use a very long wire stretched out as in Fig. 109, but to set it in the form of a very close spiral near the top of the bulb. This concentrates the brightness within a small space and may cause discomfort to the eyesight, so that most of the gas-filled bulbs are made of pearl or opal glass, whereby the light is diffused over a larger area and the glare considerably diminished without any appreciable loss of illumination.

SUMMARY OF CHAPTER XXVI.

Electric Lighting.

1. **Electric Lighting** is mainly carried out in two ways—
   - (*a*) By the passage of a strong current through a filament (either of carbon or of certain metals) enclosed in a bulb from which the air has been extracted. The current heats the filament into incandescence.
   - (*b*) By the passage of a strong current between two rods of carbon. As soon as the current begins to flow, the rods are separated a little, and as the spark leaps the gap it causes the incandescence of the carbon vapour between.

2. **Electrical Energy** is measured in watts—*i.e.*, the product of the electro-motive force and the current in the circuit.

The efficiency of a lamp is measured by the number of watts which is used to secure one candle-power of light for one hour.

Chapter XXVII

ELECTRO-PLATING

100. **Electrolysis.**—In Book II. it was shown that water could be broken up into its constituents by the passage of an electric current through it, and that oxygen was given off at one electrode and hydrogen at the other. This was called the electrolysis of water. But when we dissolve *salts* in the water and pass a current through the *solution*, the result is different.

Experiment 92.—Place the two carbon electrodes used for the electrolysis of water into a solution of copper sulphate contained in a basin or large beaker, and connect to a battery of two or three bichromate cells.

After a few minutes, one electrode will be coated with a film of copper, while a few bubbles of oxygen will be given off at the other.

Reverse the direction of the current. The copper will now gradually disappear from the electrode, on which it was first seen, *but will appear on the other*.

Experiment 93.—Substitute a plate of copper for one of the carbon electrodes, and connect this plate with the *positive* pole (*i.e.*, the carbon) of the battery, and the remaining carbon electrode with the *negative* pole (*i.e.*, the zinc) of the battery.

Copper is deposited on the carbon electrode as before, but, in this case, *the solution does not become weaker*, for as fast as the copper is removed from the solution by

this action *an equal amount of copper from the plate* takes its place.

Thus as long as the current is allowed to flow, the copper coating on the carbon electrode increases at the expense of the copper plate.

EXPERIMENT 94.—Join the wire from the positive pole of the battery to a sheet of copper (about 3″ x 2″) and the other wire to a similar sheet of tinned iron. On the latter draw a leaf (or similar pattern) and cover it with a coating of paraffin wax, leaving the rest of the tin uncovered.

Suspend the pieces of copper and tin in the copper sulphate, as shown in Fig. 111, and allow the current to

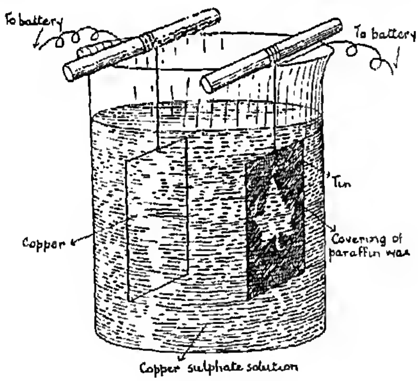


FIG. 111.

flow for a few minutes. A coating of copper will be formed on the tin, except where the coating of wax stands. When the wax is removed, the pattern of the leaf will stand out in tin against a background of copper.

NOTES.—(i.) *If both electrodes were of copper, then while the current passed, one copper plate would increase, the other diminish, the strength of the copper sulphate solution remaining unchanged.*

(ii.) *If two* silver *electrodes were dipped into a* solution of silver nitrate, *and a current passed through it, silver from the solution would be deposited on one plate and silver pass into solution from the other plate.*

101. **Electro-plating.**—The last experiment illustrates how electro-plating is carried out. Suppose it is required to nickel-plate a bicycle-bell. A bar of nickel metal and the bell (which may, for instance, be made of bronze) are arranged as electrodes in a solution of nickel nitrate (to which some ammonium nitrate is added) and the electrodes connected to the battery, taking care that the article to be coated is connected to the negative pole (*i.e.*, the zinc) of the battery. On passing the current a layer of nickel is deposited, which increases in thickness as long as the current flows.

To carry out the operation successfully, the bell must first be thoroughly cleaned. This can be done by dipping in dilute sulphuric acid, and then rinsing in warm water. Dust or grease will prevent the coating of nickel from adhering.

The correct distance between the bell and the nickel bar will be found by experience. If the electrodes are too close, the plating will be uneven; if separated too far, an excessive current is required.

The current must not be too strong, so that the deposit may be as fine and smooth as possible.

When the coating is sufficiently thick, the article must be washed, dried, and burnished.

A similar process is used for silver-plating, but the electrolyte (*i.e.*, the solution used) is usually silver and potassium cyanide. As this is highly poisonous, it is not advisable that pupils should use it.

102. **Electro-typing.**—When the first edition of a book has been printed, the printers naturally require to

use the type for other work. But it the publishers think that other editions will be required, a set of plates is prepared from which the book can be printed without using the original type. One method of doing this is by the electrotype process. An impression in wax is made of the type as it is set up. This wax impression is then electro-plated with copper, but before putting the wax in the solution, it is thoroughly brushed with *blacklead* to form a conducting surface.

When a good coating of copper is deposited, it is removed from the wax. A sheet of copper is thus obtained with letters exactly similar to the original type raised on it. The back of the sheet is strengthened by filling in with molten type metal and the plate can then be stored away ready for use when required.

The original type can then be used for other printing.

CHAPTER XXVIII

INDUCTION COILS

103. **Induced Currents.**—We have seen how an electric current can be generated by the motion of a closed coil of wire rotating in a magnetic field (*e.g.*, the armature of a dynamo), and learnt that the induced current was always accompanied by a change in the magnetic flux in the circuit. Now we shall show how one current can induce another. Study the diagram of Fig. 112. *AB* and *CD* represent two long insulated copper wires, parallel to each other, but not touching. *AB* is connected to a very sensitive galvanometer (that is, one that will respond to a very small current), while *CD* is connected to a battery and key.

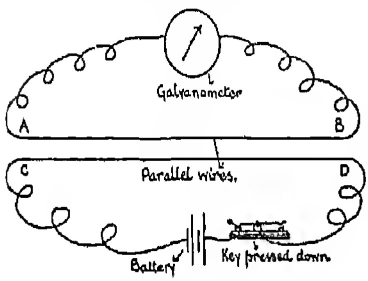


FIG. 112.

Suppose that the key is suddenly pressed down; not only does a current flow along *CD*, but also a current is induced in *AB*, for the galvanometer needle swings to one side. It, however, *immediately returns to zero*, although the current may still steadily flow along *CD*.

When the key is quickly released, the needle moves again, *but in the reverse direction.*

The circuit containing the battery is called the **primary circuit**, the other is the **secondary circuit**.

Whenever the **circuit is made** or **broken** in the primary, a **momentary current** flows through the secondary.

NOTES.—(i.) *The above cannot be carried out as an experiment, except with sufficiently sensitive apparatus.*

(ii.) *When the current is started in* CD, *a magnetic field is set up around it. This crosses* AB. *There is, therefore, a change in the state of magnetism round* AB, *and an induced current is produced in it. While the current flows steadily, there is no magnetic change, but as soon as the primary circuit is broken the magnetic field collapses; again a change takes place in the magnetism round* AB, *and an induced current occurs in the opposite direction.*

EXPERIMENT 95.—The effect mentioned in the last paragraph is much greater if coils are used instead of straight wires. If a very sensitive galvanometer is not available, and you have a reliable telephone receiver, it will serve equally well to detect the current in the secondary circuit, although it cannot indicate the *direction* of the current.

Take two cotton reels of equal size. Increase the centre hole to ½" diameter (or ⅝" if the wood is sufficiently thick in the middle) by means of a brace and bit. Cut away with a sharp penknife to give as much room between the ends as possible (see Fig. 113).

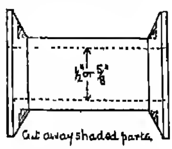


FIG. 113.

Wind one reel with as many layers as will fill it of No. 20 or No. 22 insulated copper wire, and the other with much finer wire, No. 30 or No. 36. Wind evenly and carefully. To ensure good insulation, it is a good plan to soak the wire in melted paraffin wax before beginning to wind.

Attach the ends of the thick wire to a battery and key, and the ends of the thin wire (*i.e.*, the secondary coil) to the detecting instrument, a galvanometer or telephone.

Mount the two reels on an iron rod (see Fig. 114). Every time the key is pressed or released, the circuit is made or broken in the primary circuit; and every time this occurs, a change takes place in the magnetic field, and this induces a momentary current in the secondary coil.

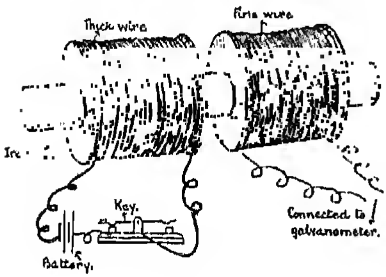


FIG. 114.

If a *telephone* is being used as a detector, a click can be heard in it every time the circuit is made or broken.

Move the reels further apart. The effect is still noticeable, although less strong.

The best results are obtained when one coil is mounted over the other, usually the secondary over the primary.

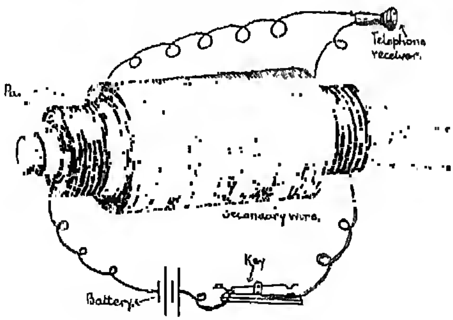


FIG. 115.

Make a paper tube to hold the iron core, and around it coil three or four layers of *thick*, insulated copper wire. Connect the ends to a battery and key.

Around this first coil of wire wrap some paper, wind several layers of *fine* wire over it, and connect the ends to the telephone receiver (Fig. 115).

The sound produced in the telephone receiver, whenever the key is pressed down or released, is now quite powerful.

104. **Variation in Current.**—Not only is an induced current obtained when the primary current *starts* or *stops*, but also when there is any **variation in the**

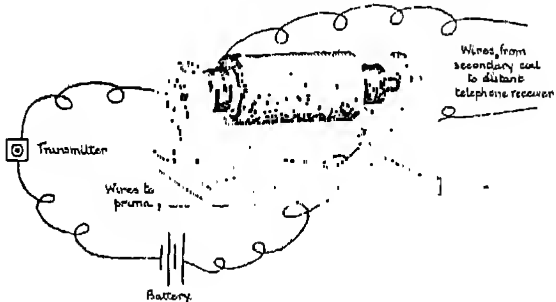


FIG. 116.

strength, so that if a telephone transmitter is attached to the primary circuit, and instead of using a key we speak into the transmitter, the variation in the current, caused by the vibration of the disc (see Paragraph 93), will cause tiny currents in the secondary coil, and these will affect the receiver attached to it.

Usually this is done in telephone circuits, and an arrangement is fitted up similar to that shown in Fig. 116. You will note that there is *no* direct connection between the battery and the distant receiver. The current flows from the battery to the transmitter, thence

to the primary coil, and back to the battery. The induced currents set up in the secondary coil alone are the cause of the action of the receiver.

The voice sounds clearer, and is heard at a greater distance, when an induction coil is included in a telephone installation.

105. **Induced Current.**—So far you have used the induced current to deflect a galvanometer needle or produce a sound in the telephone. It can also be used for two other purposes—

(i.) As a **shocking** or **medical coil.** The *current* produced in the secondary coil is always very small, but the *electromotive force* may be very high. If a pair of metal handles is attached to the ends of the secondary coil and grasped in the hands, whenever the circuit is *made* or *broken* in the primary, the *induced current in the secondary* will give a sharp, momentary shock to the nerves.

(ii.) As a **sparking coil.** If the ends of the secondary wire are held very near each other, each time a current is induced a tiny spark will leap across from one point to the other, provided that the distance is small, and a strong current is used for the primary. Very powerful coils can produce brilliant sparks more than a foot in length.

NOTES.—(i.) *In both of the cases mentioned the making and breaking of the circuit should be done many times in a second to produce a noticeable effect. The way in which this is brought about is dealt with in a later paragraph.*

(ii.) *It is not advisable to make a coil to be used both as a shocking coil and a sparking coil. A coil that will give even a small spark will give a very severe shock to anyone whose nervous system is highly strung.*

106. **A Shocking Coil.**—For the core a bar of soft iron, thoroughly annealed, is used, and over it a sheet of *smooth* paper is pasted.

On this, a paper tube is built, as indicated in Fig. 117 (*a*), which will slip easily over the core. This is placed on the winder, shown in Fig. 117 (*b*), and

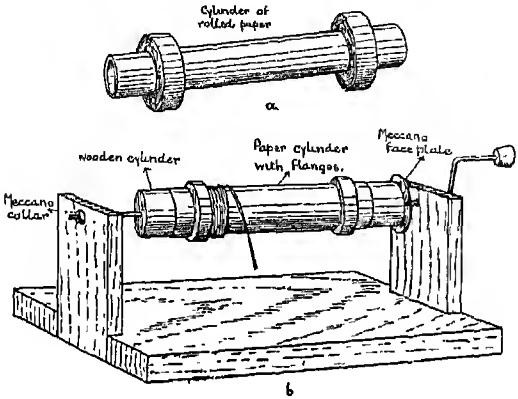


FIG. 117.

about 4 layers of thick insulated copper wire wound between the flanges for the primary.

Another pap er tube is then built up over the primary tube, and from 10 to 20 layers of *fine* wire placed between

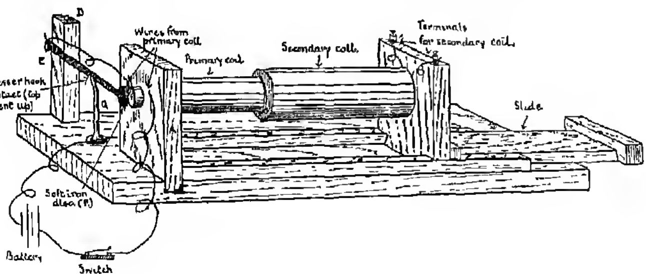
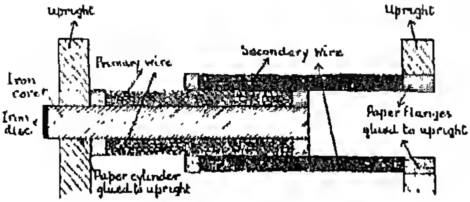


FIG. 118.

the flanges. The layers of wire should be thoroughly insulated from each other by inserting a sheet of thin, waxed paper between them.

The two coils are mounted on upright pieces of wood, as shown in Fig. 118, and so arranged that the secondary coil can slide over the primary. The ends of



Section through Coils

FIG. 119.

the wires are brought to suitable terminals, as shown. A section through the coils is given in Fig. 119.

Directions for the construction of the various parts are given in Chapter XXX.

107. **The Interrupter.**—It will be evident that for successful working, the making and breaking of the circuit must be done very rapidly, far more quickly than can be carried out by hand. For this, we can make use of the principle of the electric bell, in which the "make and break" occurs many times a second.

Fig. 118 shows a simple arrangement which will remind you at once of your electric-bell model.

F is a piece of soft iron, soldered to a piece of springy brass *E*, which is screwed to a wooden pillar *D*. *G* is a brass picture-hook, which lightly touches *E*, and so arranged that, by turning it to the left or right, the position of *F* can be altered, bringing it nearer to the core or farther from it.

The connecting-up to a battery and switch is indicated in the diagram. When the connections are made, and the switch closed, a current flows through the primary coil, magnetizes the core, which attracts *F*,

thus breaking the circuit. The spring flies back, contact is once more made, and the process is thus repeated again and again.

Handles can be made of thin brass tubing, and connected by stout wires to the secondary coil terminals on *B*. If these are grasped, one in each hand, and the key is depressed, the induced current will flow through the body in a series of tiny shocks, the strength of which will depend on the battery current. A bichromate cell should be quite strong enough with the coil just described. Before giving anyone a shock from such a coil, the secondary coil should be pulled out to its farthest extent, to obtain only a weak effect. Then when the handles have been grasped, the coil can be pushed in until as much strength is obtained as the holder can endure.

NOTES.—(i.) *An important consideration in the making of induction coils is to secure perfect* **insulation**. *One of the best substances to use is* **paraffin wax**. *Care should be taken in melting it to ensure that it does not burn. A suitable method is to stand the vessel containing the wax in an outer vessel filled with hot water. The whole of the wire, before being coiled, should be dipped in the melted wax and then suspended over it to drain. The paper tubes, on which the wire is wound, should also be given a coating by means of a soft brush.*

(ii.) *Whilst a* **shocking coil** *can be made satisfactorily by an average boy, he should attempt to make a* **sparking coil** *only if he has plenty of time and patience, and can exercise great care in his work. A large amount of wire is necessary, and unless precautions are taken to obtain a very good insulation, sparks will leap from one defective spot to another and cause a breakdown. The principle of the sparking coil is the same as that of the shocking coil, but it contains in addition a* **condenser**, *the form and use of which can be studied from more advanced textbooks.*

(iii.) *Induction coils are required for the production of X rays, and are also much used in wireless telegraphy.*

SECTION VI.—APPLICATIONS OF HEAT

CHAPTER XXIX

THE STEAM ENGINE

108. **The Expansive Force of Steam.**—Before starting to study the steam engine, let us revise some facts we studied in Book II.

When water is heated it rises in temperature until it reaches the **boiling-point** (normally 100° C. or 212° F.). Then, although heat still continues to pass into the water, *its temperature does not rise any further*—the heat energy being used in converting the water into steam. The heat, thus used, we called the **latent heat of vaporization.**

In this process, **an enormous expansion** takes place (that is, provided the space is available for the expansion), **1 volume of water becoming 1,600 volumes of steam.**

What would happen if the steam were prevented from expanding? It would still *try* to do so, and the more heat energy it received, the greater would be the amount of water converted into steam and the greater the expansive force, the result being that a very great pressure would be set up inside the containing vessel.

NOTE.—*In Book II. you learnt that under diminished pressure water will boil at a temperature less than* 100° C. *The converse is true—that when water is heated in a confined space, with the*

increase of pressure of the air and vapour above it, the boiling-point rises. In such a confined space, in a very strong vessel, the temperature may become 200° *C., when the pressure would be equal to about* 16 *atmospheres*—i.e., 16 *times as great as the normal pressure of the air.*

In a steam engine such pressure can be made to do useful mechanical work—that is, the *heat energy* supplied by the steam can be converted into *mechanical energy*.

The object of the engineer is to utilize the heat energy to the best advantage. His problem is—

(1) To produce steam in large quantities, *without waste of fuel.*

(2) To prevent the steam from expanding until it has sufficient pressure to do the work, at the same time guarding against the development of a pressure too great for the strength of the boiler.

(3) To control and direct the expansion so as to produce motion.

109. **Production of Steam.**—When we heat a kettle over a fire or a gas ring, in order to boil water, a large amount of heat is wasted.

As an engineer cannot afford to waste heat, he fits his boiler right round the fire, and has a flue running up through the middle.

In Fig. 120 *a* and *b* are shown diagrams of two very simple boilers, one with a large flue through the middle and the other with several smaller tubes.

NOTE.—*These diagrams simply show sections of the boilers; many necessary parts are left out.*

Both these boilers are cylindrical, and are of the type used for stationary engines. For locomotive engines the boiler is horizontal and of different design.

In modern boilers the number of tubes is increased until the boiler consists almost entirely of tubes. Such boilers are called **multitubular boilers**, and the water

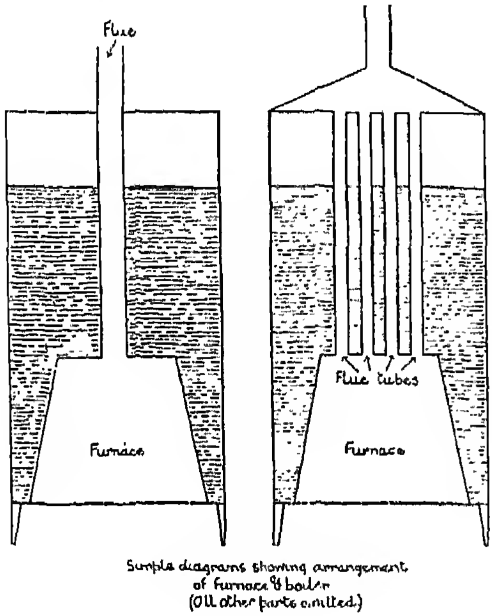


FIG. 120.

in them can be heated very rapidly without much waste of fuel.

A water gauge (Fig. 121), as described in Book I., is used to show the amount of water in the boiler. **Boilers must never be allowed to become empty** while being heated.

110. **Preventing Steam from Expanding.**—If water were heated strongly in a closed boiler the steam would in time burst the boiler, unless it were exceedingly strong. It is, however, easy to build a boiler strong

enough for our purposes. A cylindrical one is better than any other.

All boilers are provided with what is called a **safety valve.** The steam is enclosed in the boiler until it has pressure enough to drive the engine. If the pressure becomes greater, the valve is lifted and steam escapes.

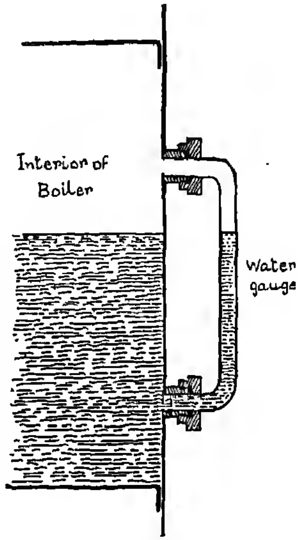


FIG. 121.

How is this done? The valve (see Fig. 122) is shaped like a cone, and fits into an opening in the top of the boiler. It is kept in position by a long hinged bar with a weight at the end. You know from your previous work, that by moving this weight along, the force with which the valve is pressed down can be altered. When the upward force of the steam is greater than the force downward on the valve, the valve is lifted automatically. Some

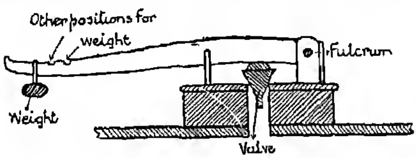


Diagram showing principle of safety valve

FIG. 122.

safety valves have a spiral spring attached below the cone instead of the bar and weight above.

Controlling the Steam.—This is the most difficult

problem of the three. Before we control the steam we must know what we want it to do. In most cases, its work is evidently to drive wheels.

EXPERIMENT 96.—Obtain a round tin and cut out a circular piece of wood which will just fit into it lightly. Put a screw in the middle of one side to act as a handle.

Pour about an inch of water into the tin, and press the wooden plunger down until it is about half an inch above the water. Place the tin over a Bunsen burner. As the water boils, the plunger is lifted.

This is similar to what takes place in an engine. The circular tin represents the strong metal cylinder of the engine, and the wooden plunger the piston which fits the cylinder accurately. The chief differance is that in the engine, the water is not boiled in the *cylinder*, but in a separate boiler from which the steam passes along pipes into the cylinder.

We will suppose that the steam in the boiler is at a high pressure—that is, it has been strongly heated without being allowed to expand. At the right

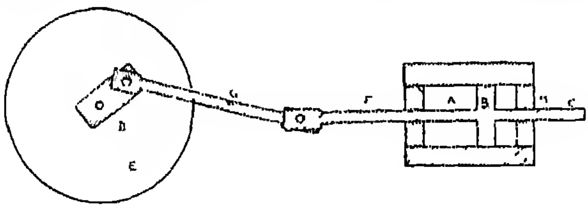


FIG. 123.

moment it is admitted into the cylinder. Here it *can* expand, but only by pushing the piston along.

The work of the steam is to produce the movement of the piston.

The difficulty of turning wheels is not solved yet.

EXPERIMENT 97.—Make in cardboard the apparatus shown in Fig. 123 (full details of construction are given in Chapter XXX.). By making and working it you should get a clear idea of how the *to-and-fro motion* of the piston can produce the *revolution* of a wheel.

A	represents	the	cylinder.
B	,,	,,	piston.
D	,,	,,	crank.
E	,,	,,	fly-wheel.
F	,,	,,	piston-rod.
G	,,	,,	connecting-rod.

The part *C* is added so that you can move the piston backwards and forwards. In an engine, this, of course, would be done by the steam.

Now move *C* forward and back. The end of the connecting-rod *D* is forced to turn in a circle, because it is fixed by the crank to the fly-wheel.

Suppose steam had been forced in through the hole *H*. It would have done just what you did when you moved *C* forward. It could not, however, pull *C* back again as you were able to do.

This difficulty is overcome in an engine in two ways:

1. **By making the fly-wheel push the piston back.**

When a heavy wheel has been set revolving, it does not stop suddenly as soon as the force is removed, but continues to turn *for a little while.* This motion in the fly-wheel is sufficient to push the piston back, if at that moment the pressure of the steam has been cut off from the piston and the steam already in the cylinder can escape.

Look at the two sketches in Fig. 124. If the taps are turned on and off alternately, the sketches explain for themselves how the piston is moved.

Remember that the fly-wheel pushes the piston back. This is called a **single acting cylinder.**

In the early days of the steam-engine a boy was

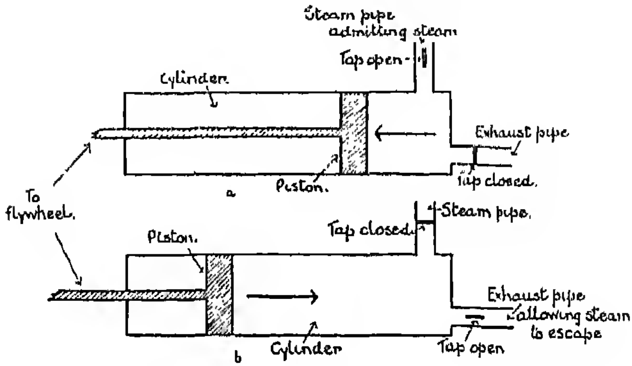


FIG. 124.

employed to turn the taps on and off. Nowadays it is done automatically.

III. **The Oscillating Cylinder.**—Many of you possess a working model of an upright steam-engine, or, if not, you have all seen one in a shop-window. In most cases, you will notice that as the piston-rod moves up-and-down (thus causing the fly-wheel to revolve), the **cylinder itself moves** with a swinging motion to-and-fro. We say that the cylinder **oscillates**, and thus such a type of engine is said to have an **oscillating cylinder.**

You also know that as soon as there is sufficient pressure of steam in the boiler and the steam-cock is turned on, admitting the steam to the cylinder, the engine begins to work and goes on working for some time. We wish to discover how the steam is automatically admitted and shut off from the cylinder, and how it escapes when it has done its work. To understand this, let us make another simple model.

EXPERIMENT 98.—Cut out the two pieces of cardboard, as shown in Fig. 125 (details are given in Chapter XXX.). On the piece *A*, two circles, one coloured red and one blue, are drawn.

On the piece *B*, there is a hole of the same size as the coloured circles.

Fit *B* over *A*, and fasten together with a paper-fastener, as shown in the diagram.

Move *B* to-and-fro as a pendulum.

The red and blue circles show alternately through the holes.

Now imagine that *A* is a thick plate of metal, and that the red and blue circles are openings from two tubes at the *back* of *A*—one tube (the steam pipe) bringing steam from the boiler, the other (the exhaust pipe) allowing steam to disperse in the air.

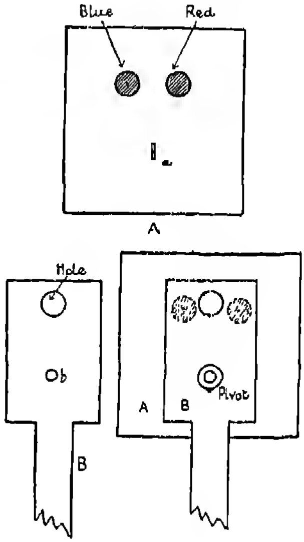


FIG 125.

Let the **red circle** represent the **steam-pipe**.
,, **blue** ,, ,, ,, **exhaust** ,,

Imagine also that *B* is another block of metal with one hole, as shown, and that this hole leads right into the top part of the cylinder. *B* can swing by means of the pivot to-and-fro over *A*, but the two faces are supposed to slide so accurately over one another as to be "**steam-tight**," that is—no steam can escape between them.

When the hole in *B* is over the red circle, steam can

enter the cylinder but none can leave, as the blue circle is shut off. Similarly, when the blue circle is uncovered, steam can leave the cylinder but none can enter.

Fig. 126 shows you that if the piston-rod is joined

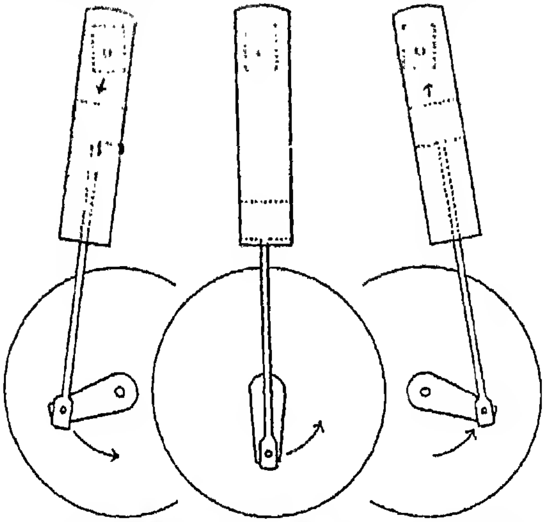


FIG. 126.

by a crank to the fly-wheel, when the wheel is turned the cylinder must swing like a pendulum.

(*a*) Shows the cylinder in such a position that steam is admitted, forcing the piston down and the cylinder into the position shown on (*b*).

In (*b*) no steam is admitted, and the impetus of the fly-wheel carries the cylinder into the position shown in (*c*) when the steam escapes, and back to (*a*) when more steam is admitted.

This is a **single acting oscillating cylinder.** The lower end of the cylinder is open.

ıe to the second method of pushing the (You can easily see objections to the scribed. The great one is that the fly- robbed of its energy.)

g steam on both sides of the piston

· 99.—Cut out the pieces of cardboard, 'ig. 127 (full details of construction are

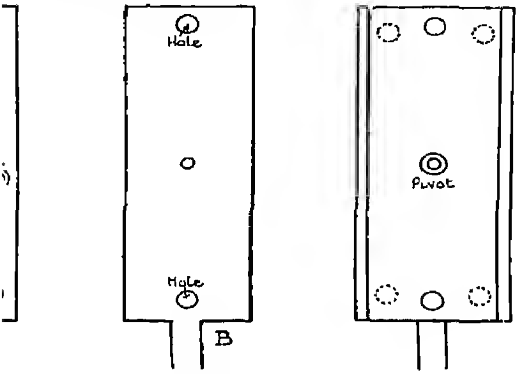


FIG. 127.

er XXX.). Pivot *B* on *A* as before and side to side. As *B* swings to the left, $)_1$ and the blue circle C_1 appear through

to the right C_2 and D_2 appear.

.n the last experiment, that *A* is a fixed with holes at C_1, C_2, D_1 and D_2, to which ı pipes at D_1 and D_2 and exhaust pipes

; the cylinder which fits tightly against d is pivoted to it.

: must be closed at both ends.

op of the cylinder swings to the right,

steam is admitted at D_1, pushing the piston down. This forces the crank around (see Fig. 126), and the cylinder swings to the left. The steam in the cylinder is now free to escape at C_2, and steam enters below the piston at D_2, forcing the piston up again. These two operations continue.

In this case, the piston is *driven* both ways, and the cylinder is called a **double acting oscillating cylinder.**

It is easy to see that the oscillating cylinder, although a clever device, is not perfect. It would be much better to have the cylinder fixed.

112. **The Slide-Valve.**—The most common form of engine now in use has a fixed cylinder, and the device that is used for admitting the steam and allowing it to escape is called a slide-valve.

As with the double acting oscillating cylinder, there are entrances for steam to each end of the cylinder and an exit for the exhaust steam, which automatically connects to either end.

A simple model will show you how this valve acts.

EXPERIMENT 100.—Cut three rectangular holes in a

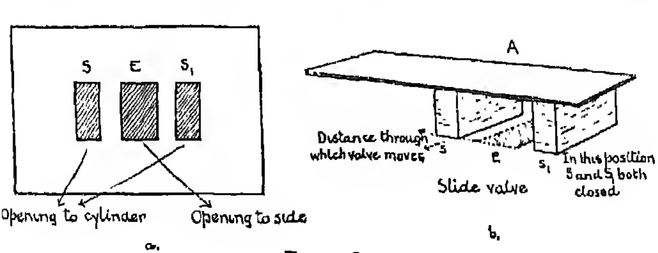


FIG. 128.

piece of cardboard as indicated in Fig. 128 (*a*). This represents a thick flat plate fastened to the top of the cylinder [see Fig. 129 (*a*)]. The two outer openings,

S and S_1, communicate with the interior of the cylinder, and the central opening E leads to the outside air only.

Take two pieces of wood just thick enough to cover the width of the holes S and S_1, and a little longer than is necessary to cover the length. Nail a piece of cardboard on top of them in the position shown in Fig. 128 (*b*).

This represents the slide-valve. In an engine the piece of cardboard would be replaced by a rod, and a box called the valve-chest would be fitted right over the slide-valve. There would be one hole in the side of the box through which the rod would pass, and another hole in the top to which would be attached a steam-pipe [see Fig. 129 (*b*)].

The sides of the valve, between the struts of wood,

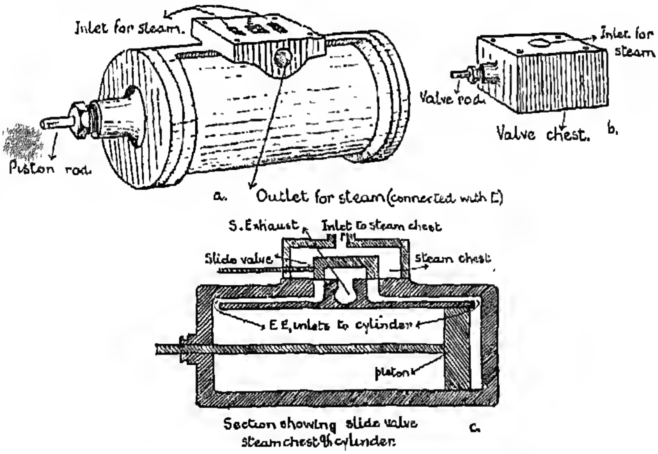


FIG. 129.

would be enclosed so that no steam could pass to E directly from the valve-chest.

Fig. 129 (*c*) shows a section of a cylinder, slide-valve, and valve-chest in position. Study it carefully.

113. **Action of the Valve.**—Place your model valve on the cardboard so that the wooden struts cover the holes S and S_1. (Remember all the time that in an engine this valve is working in a box containing steam which presses it down tightly on the cylinder.)

Move the valve forwards and backwards, just the width of the holes S and S_1.

Notice that there are three positions:

(*a*) When S and S_1 are both closed.

(*b*) When S and E communicate inside the valve, and S_1 is open to the steam in the valve-chest.

(*c*) When S_1 and E communicate inside the valve, and S is open to the steam in the valve-chest.

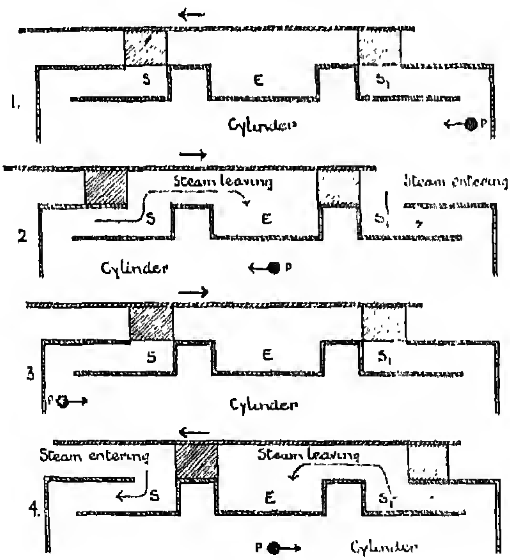


FIG. 130.

Now study the positions of the valve shown in the four diagrams of Fig. 130. The arrows indicate the

directions in which the slide-valve and piston are moving.

Position 1.—The cylinder is shut entirely, and no steam can enter or escape. The piston momentarily does not move in this position.

Position 2.—Move the slide-valve along. Steam is admitted at S_1, pushing the piston (P) along in the direction of the arrow, and allowing waste steam to escape through S to E (the exhaust).

Position 3.—Move the slide-valve back to the position of 1. The cylinder is shut entirely, and the piston does not move.

NOTE.—*In positions* 1 *and* 3 *you notice the piston is at the end of the cylinder.*

Position 4.—Move the slide-valve farther back. Steam is now admitted at S, pushing the piston in the direction of the arrow, while exhaust steam can escape through S_1 to E.

You will have probably noticed, in examining the diagrams of Fig. 130, one interesting point about the movements of the slide-valve and the piston—*they are not always in the same direction*:

In 1.	Slide-valve	moves	*back;*	piston	moves	*back.*
2.	„	„	„ *forward;*	„	„	„
3.	„	„	„ *forward;*	„	„	*forward.*
4.	„	„	„ *back;*	„	„	„

This is necessary in order that the steam may enter the cylinder at each end *at the right moment.*

Yet the movement of the piston-rod causes the movement of the valve-rod too. The next paragraph will explain how this is done.

114. **The Eccentric.**—Look again at the model shown in Fig. 123, in which the crank (owing to the

movement of the piston) causes a fly-wheel to revolve, and compare it with Fig. 131, which shows you the

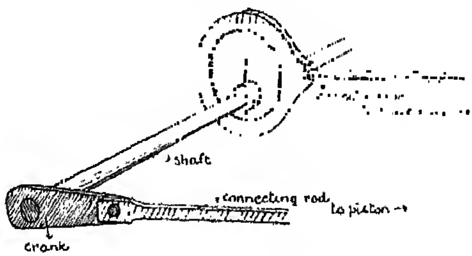


FIG. 131.

crank, not joined to a fly-wheel, but to a heavy rod, called the **shaft**. On the shaft, the driving wheels are fixed, and rotate with it. (A fly-wheel may also be mounted on it, to keep the motion steady.)

But on this shaft can also be seen a very peculiar wheel. Examine it closely, for it is the 'Key' to the slide-valve. A diagram is given in Fig. 132.

You will notice that **the shaft does not pass through**

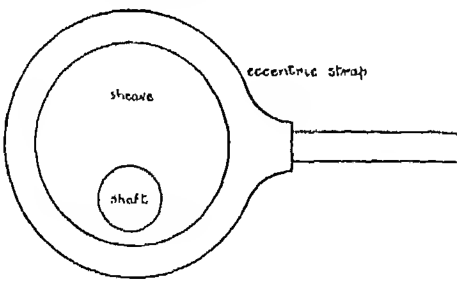


FIG. 132.

the centre of this wheel. The wheel is, in consequence, called an **eccentric** (out of the centre).

There is another peculiarity about it. There are two parts to it, the **sheave** (fixed *to* and revolving *with* the

shaft) and the strap which is *not* fixed to the sheave, but forms a well-fitting ring around it. To the strap is connected a rod, called the valve-rod (see Fig. 131), which moves the slide-valve to and fro.

You will see that if the shaft were in the centre of the eccentric, the inner part—the *sheave*—would revolve with the shaft, but the outer part—the *strap*—would not move.

But what effect has the rotation of the shaft now? Look at Fig. 131 again. The main portion of the sheave is shown *above* the shaft, but as it revolves with the shaft, it will sometimes be at the side and sometimes below.

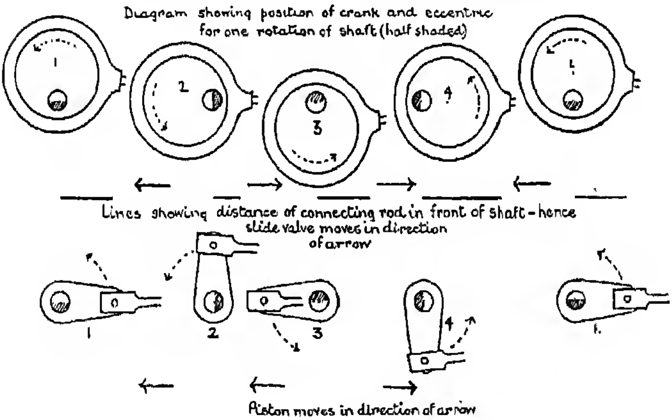


FIG. 133.

There are four such positions shown in Fig. 133, where the actual position of the shaft is understood to remain the same, but the bulk of the eccentric alters in position as it revolves.

Carefully note how the connecting-rod (or valve-rod) is attached to the strap. It does not rotate around the shaft, but has a *forward* and *backward* motion almost

in a straight line. Its position will depend on where the main portion of the eccentric happens to be at any particular moment. In the second position of Fig. 133, it is as close to the shaft as it can be, in the fourth position it is as far away to the right as it can be.

Study again the five small diagrams of Fig. 133. These represent one turn of the crank (shown in the lower portion) and of the eccentric shown above. Notice—

(1) The valve-rod moves through a smaller distance than the piston-rod.

(2) It does not move "in time" with the piston-rod.

The arrows in dotted lines show the direction of revolution. As the position of the crank changes—

(*a*) From (1) to (2), the piston moves backward, the slide-valve backward.

(*b*) From (2) to (3), the piston moves backward, the slide-valve forward.

(*c*) From (3) to (4), the piston moves forward, the slide-valve forward.

(*d*) From (4) to (5) the piston moves forward, the slide-valve backward.

This is in agreement with the results of your experiment with the cardboard model and the diagrams in Fig. 130.

You should thus be able to understand how the motion of the slide-valve can be adapted to the motion of the piston, so that the steam can enter the cylinder at the right moment. You must bear in mind, that all the drawings are very much simplified. In an actual engine the arrangements are more elaborate, but if you are privileged to examine one, you should now know sufficient to understand something of its working.

NOTES.—(i.) *There is often an addition to the slide-valve, which enables an engine to work either backwards or forwards—a* **reversing gear.**

(ii.) *Some engines have three cylinders. The steam is at very high pressure, and after passing through the first cylinder still retains a considerable pressure, which is used to work the piston in the second cylinder. The steam, issuing from this cylinder, though of much less pressure than at the beginning, is again used in a third cylinder, before passing out into the air. These engines are called* "**triple expansion**" *engines.*

(iii.) *When the steam has done its work in the cylinders, it is not always allowed to pass into the air, but is led into a* **condenser,** *where it is condensed into water. This water soon reaches a high temperature, and if pumped back into he boiler, requires much less heat to turn it into steam than an equal quantity of cold water. This ensures a saving of fuel.*

SUMMARY OF CHAPTER XXIX.

The Steam Engine.

1. When water is converted into steam by the application of heat, a very great expansion takes place. The expansive force of steam can be made to do work.

Thus, **heat energy** can be changed into **mechanical energy.**

2. In modern boilers, as much *heating surface* as possible is obtained. The water to be heated surrounds a large number of tubes, through which the flames and heated gases pass.

3. The steam is *confined* in the boiler until a sufficient pressure is reached. To prevent the pressure from becoming too great, and therefore dangerous, a **safety-valve** is used.

4. The steam at high pressure is allowed to pass into the **cylinder** and push a **piston** along it. By means of a rod and crank, this movement of the piston can be made to turn a wheel and thus do work.

5. To produce a continued movement of the piston, the **oscillating cylinder** and the **slide-valve** have been invented.

6. In the **single oscillating cylinder**, the steam forces the

piston in one direction only. The return movement is caused by making the fly-wheel push the piston back.

7. The slide-valve is an arrangement which allows the steam to enter *at each end* of the cylinder at the appropriate moment, and also allows the used steam to escape. The steam thus pushes the piston in both directions.

8. The automatic action of the slide-valve is produced by the action of the eccentric.

SECTION VII.—MAKING OF MODELS

CHAPTER XXX

MODELS

NOTE.—(i.) *In the third-year course of model-making in this chapter you will find that the directions have been reduced, and that you will often be called upon to read your instructions from drawings. Study the drawings carefully.*

(ii.) *In all models, dimensions for wood are finished dimensions. Allow for waste in cutting out.*

1. Callipers.

Material required:

1 piece $\frac{3}{4}'' \times \frac{1}{16}''$ mild steel strip 14″ long.

2 pieces $\frac{1}{8}''$ diameter iron rod $\frac{3}{8}''$ long.

1 piece of cardboard.

With a scriber set out on the mild steel strip the shapes shown as *A* and *B*, Fig. 134, and two $\frac{3}{4}''$ diameter circles. The lengths of *A* and *B* are only approximate.

File these two pieces out roughly to shape, and the two circles exactly.

Drill $\frac{1}{8}''$ holes in *A* and *B*, in the position shown in the figure, and roughly rivet together with one of the pieces of iron rod.

Draw on the cardboard the finished shape of one arm of the callipers (shaded in Fig. 134). **Cut this out carefully.**

NOTE.—*It would, of course, be better in every way if the template were made of tinplate; but a pair of curved shears would be required for this, and the ordinary school workshop is not supplied with this tool.*

Fix a piece of gas barrel, say 1″ or ¾″ diameter in the vice.

Heat one of the straight arms to a dull red, and with a hammer tap it round to the required shape, testing with the cardboard template.

Repeat this process with the other arm.

When both are satisfactory, knock out the rivet, and file up exactly to shape, again testing frequently with the template.

Drill a ⅛″ hole through the centre of each of the circular pieces (the washers).

Place one on each side of the arms in position, and rivet together.

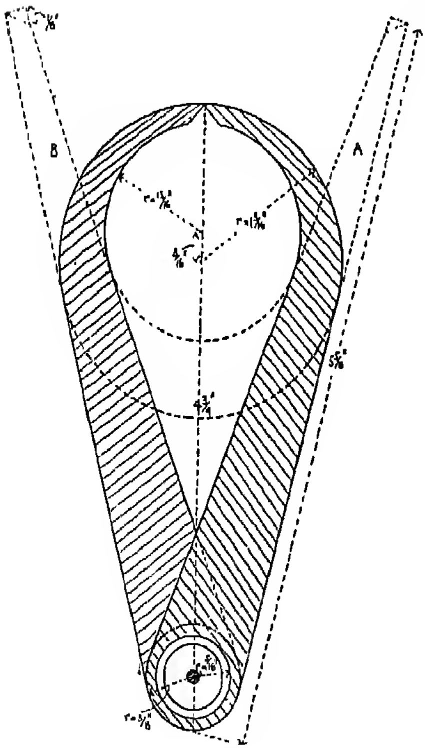


FIG. 134.

Tap a slight bend inward on each arm, so that the two points meet.

2. Screw Gauge.

Material required:

1 piece basswood, $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$.
1 ,, ,, $4'' \times 1\frac{1}{4}'' \times \frac{1}{4}''$.
1 ,, ,, $2'' \times 1\frac{1}{4}'' \times \frac{1}{4}''$.
1 ,, ,, $1\frac{1}{4}'' \times 1\frac{1}{4}'' \times \frac{1}{4}''$.
1 $\frac{1}{4}''$ Whitworth bolt and nut (bolt assumed to be $2''$ long).
1 piece sheet brass, $1''$ square, $\frac{1}{16}''$ thick.
$\frac{1}{2}''$ oval brads.

With this model particularly, study the sketch shown in Fig. 135, because if the $\frac{1}{4}''$ Whitworth bolt you have does not happen to be $2''$ long, the position of the support in your model may require alteration.

The piece of wood $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ is chamfered on three edges to form the base-board.

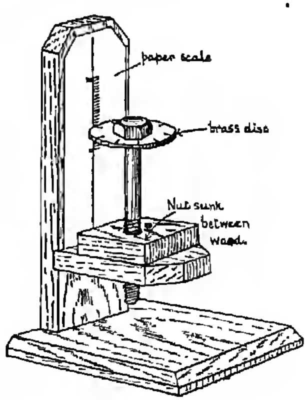


FIG. 135.

The piece of wood $2'' \times 1\frac{1}{4}'' \times \frac{1}{4}''$ is to form the support of the bolt, and has to be grooved into the piece $4'' \times 1\frac{1}{4}'' \times \frac{1}{4}''$ (the upright.)

Note again. The drawings for this construction are made on the assumption that the bolt is $2''$ long, and that the screw thread occupies $1''$ of this.

Set out the piece of wood $4'' \times 1\frac{1}{4}'' \times \frac{1}{4}''$ according to the dimensions given in Fig. 136. Cut the dovetail and the groove.

Above the groove paste a piece of paper, of the shape shown in the figure, and draw a vertical line in the centre.

Remove the hexagonal nut from the bolt, and place it on the face side of the piece of wood $2'' \times 1\frac{1}{4}'' \times \frac{1}{4}''$, in the position shown on Fig. 136 (*b*). Mark around it with a sharply pointed pencil, pointing the pencil inwards the whole time.

Draw two diagonals of this hexagon to find the middle point, and with this point as centre bore a $\frac{1}{4}''$ hole perfectly vertically in the wood until the point of the bit protrudes on the other side.

Before completing the boring, cut a hexagonal hole $\frac{1}{8}''$ deep, working just inside your pencil lines.

Complete the boring of the $\frac{1}{4}''$ hole.

Repeat this process exactly with the piece of wood $1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{4}''$, placing the nut with its

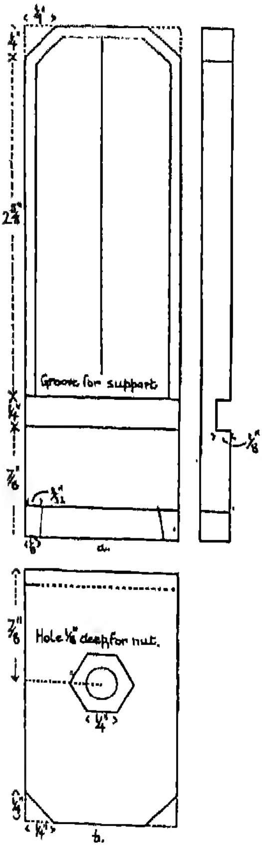


FIG. 136.

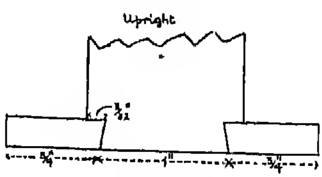


FIG. 137.

middle point directly over the point of intersection of the diagonals drawn on the face side.

In the middle of that edge of the baseboard which is not chamfered, cut a dovetail socket $\frac{1}{4}''$ deep to fit the upright (Fig. 137).

NOTE.—*Mark the width on the upright from the dovetail.*

Glue and brad the upright into the baseboard, and the support into the upright.

Now fit the nut into the hole in the support, invert the other piece of wood over it, screw in the bolt and test that it is vertical. If it should not be correct, adjust the depth of the hole in the support until it is.

Glue the two pieces of wood together.

NOTE.—*The nut may be a little too thick to allow the two pieces of wood to touch. If that is so, deepen the hole on the top piece only.*

Set out on the piece of sheet brass a circle $\frac{3}{4}''$ diameter. File to shape, drill a $\frac{1}{4}''$ hole through the centre.

Slip the disc on the bolt until it touches the head, and solder it to the bolt.

NOTE.—**It is essential that the disc should be accurately at right-angles to the bolt. If it is the least bit out, remove the solder and try again.**

Screw the bolt through the nut until it just touches the baseboard. Mark, with a short radial line on the brass disc, the point that touches the line on the upright. From this point, divide the circumference into ten equal parts with short radial lines, and number them from 0-10 in the direction of the movement of the hands of a clock (original point 0).

Mark the scale as indicated in Chapter I.

3. Wire Stand for Lens.

Material required:

2 pieces of stout insulated wire 11″ long.

Double each piece of wire, and hold them together with the looped ends in the same direction.

FIG. 138.

Hold the four strands firmly $1\frac{1}{4}''$ from this end with a pair of flat-nosed pliers. Bend the double strands outwards, and then twist them together until $1\frac{1}{2}''$ remains untwisted.

Bend the four untwisted ends out at right angles, as in Fig. 138, to form a stand. Pull the two doubled ends apart, and then bend them slightly, forming a **V**-shape with the sides a little curved (Fig. 138). Open each double strand sufficiently for the edge of a lens to pass between the strands.

4. Stand for Revolving Glass Prism.

Material required:

1 piece basswood, $9'' \times 2'' \times \frac{1}{4}''$ (waste allowed for).
1 ,, ,, $3'' \times 2'' \times \frac{1}{4}''$ (waste allowed for).
6 small basswood blocks, $\frac{1}{2}'' \times \frac{1}{4}'' \times \frac{1}{4}''$.
1 piece $\frac{3}{8}''$ dowel stick, $3''$ long.
1 glass prism or "lustre" from an old glass ornament (assumed to be $3''$ long and with section an equilateral triangle with $\frac{3}{4}''$ sides.)

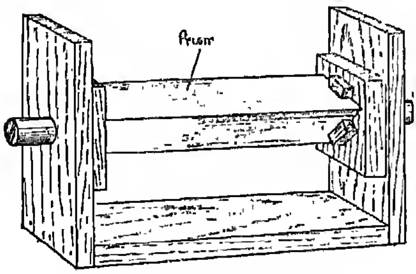


FIG. 139.

From the piece of wood $9'' \times 2'' \times \frac{1}{4}''$, making cut lines at right angles, cut out two pieces $2\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$ and

one piece $3\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$. Cramp the two $2\frac{1}{2}''$ pieces together with their face sides touching, and on the middle line $\frac{3}{4}''$ from one end bore a hole with a $\frac{3}{8}''$ bit through both.

Brad the other ends of the two pieces to the ends of the piece $3\frac{1}{2}''$ long to form the baseboard and uprights as in sketch.

Set out the piece $3'' \times 2'' \times \frac{1}{4}''$, as shown in Fig. 140,

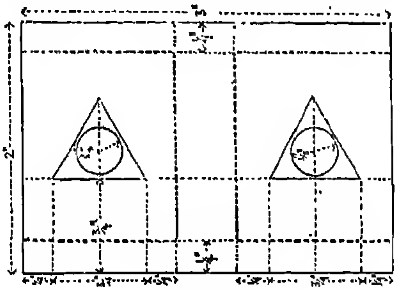


FIG. 140.

bore the two $\frac{3}{8}''$ holes in the position shown, and cut along the thick dotted lines into two pieces, $1\frac{1}{2}'' \times 1\frac{1}{4}'' \times \frac{1}{4}''$.

Cut the $\frac{3}{8}''$ dowel stick into two equal pieces, and glue a piece into the hole in each of these two pieces of wood. The end of the dowel stick in each case should be flush with the face side of the wood.

When dry push the other end of each dowel through the $\frac{3}{8}''$ holes in the uprights (from the inside)

Place the prism between the two pieces of wood, to which the dowels are attached, so that the ends of the prism are exactly on the equilateral triangles drawn on the wood.

Support the prism in this position, and glue the small blocks round, as shown in Fig. 139.

Leave in the support until dry.

5. Electric Motor.

Material required:

1 cylindrical piece of wood ($\frac{3}{4}''$ diameter) $6''$ long, from which 2 pieces $\frac{5}{8}''$ long are cut off.
1 piece wood, $8'' \times 4\frac{1}{2}'' \times \frac{1}{2}''$.
2 pieces strip iron or *stout* tinplate, $8'' \times \frac{3}{4}''$.
2 pieces tinplate (from an old tin), $2\frac{1}{4}'' \times 1\frac{1}{4}''$.
1 piece thin brass or copper tubing, $\frac{3}{8}''$ to $\frac{5}{8}''$ bore.
1 cylindrical piece ebonite (from round ruler) or any hard wood to fit the bore of the tubing, $\frac{3}{4}''$ long.
1 piece $\frac{1}{16}''$ brass strip, $\frac{3}{4}'' \times 3\frac{1}{2}''$.
2 pieces sheet brass (26 or 28 gauge), $2\frac{1}{2}'' \times \frac{1}{2}''$.
1 *fine* $2''$ screw.
1 ,, $1''$,, (same diameter).
Reel of No. 22 D.C.C. wire.
Strips of binding cloth for insulating purposes.
2 terminals.

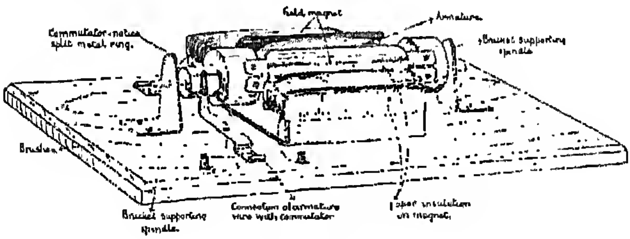


FIG. 141.

1. **Field Magnet.**—Cut lines with a scriber at right angles across one piece of strip iron, as in Fig. 142 (*a*) place the two pieces together, and make right-angle bends, to the shape shown in Fig. 142 (*b*), with a vice and flat-nosed pliers.

Tap the flanges on the long cylinder of wood until they are shaped as in Fig. 142 (*c*).

The two arms marked *A* and *B* are to be wound to form the field magnet, but before doing so insulate them thoroughly by winding strips of binding cloth

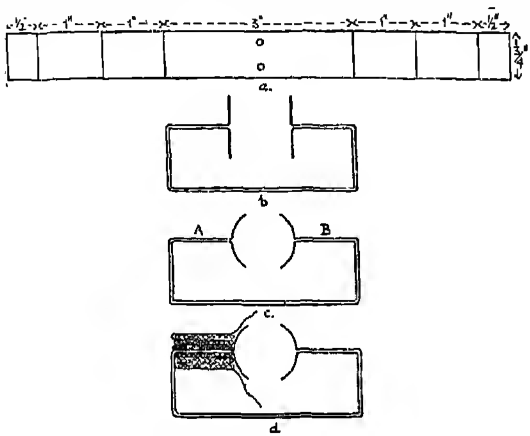


FIG. 142.

around them. If no cloth is available, use two or three layers of paper, well gummed down.

Wind five or seven layers of wire evenly around each arm, taking care that on crossing from *A* to *B* the wire is wound in the correct direction. The rule for this is given in Book II., p. 62.

NOTES.—(i.) *The wire can be much more evenly wound and secured in its place if tape is inserted between the layers, as indicated in* Fig. 142 (*d*).

(ii.) *When one arm is finished, secure the wire by strong thread before proceeding to the other arm.*

(iii.) *When both coils are wound, they may be glued. This prevents the coils from becoming loose, and also aids insulation.*

2. **The Armature.**—Set out the two pieces of tin-plate with a scriber, as shown in Fig. 143 (*a*). Cut along the dotted lines, and bend the shaded portions

over the central portion until they lie quite flat. Tap them down if necessary.

Drill holes for small $\frac{3}{8}''$ screws, as indicated.

Take the long wooden cylinder and saw across the diameter lengthwise for a distance of $2\frac{1}{4}''$.

In this slot place each of the pieces of tinplate in turn, and hammer the flanges over the rounded portion, as shown in Fig. 143 (*b*).

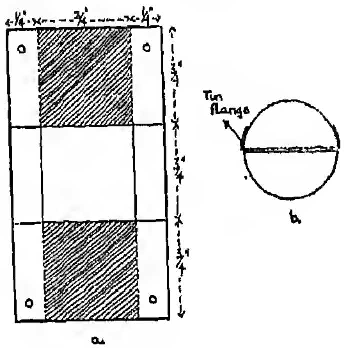


FIG. 143.

Place the two pieces of tinplate back to back, and bind the central portion (where there will be six thicknesses of tin) with binding-cloth. Cover with gum or gummed paper all tinplate that is likely to come into contact with wire.

Now wind the armature with about 6 to 8 layers of No. 22 or 24 D.C.C. wire, finishing at the end you began.

NOTE.—*Leave about* $1\frac{1}{2}''$ *to spare at beginning and end for connections.*

Take the two cylindrical pieces of wood, $\frac{3}{4}''$ diam., $\frac{5}{8}''$ long, push them (one at each end) between the projecting ends of the armature, with the curved surfaces resting on the flanges, and screw the latter to the wood.

3. **The Commutator.**—File down the piece of ebonite or hard wood until it exactly fits in the brass tube. Cover the surface of the ebonite with cold glue, and push it into the tube.

Drill a $\frac{1}{8}''$ hole exactly through the centre of the ebonite, and screw the $2''$ screw into the hole until it protrudes $\frac{1}{2}''$.

Place the tube in a vice, and with a hack-saw split the brass tube lengthways into two pieces, of semi-circular section (see Fig. 94). (Be careful not to saw into the ebonite.)

Bore a hole *exactly* in the centre of the wooden end of the armature nearest the ends of the wire, and screw the commutator in the hole until the brass sections touch the armature. Drill two fine holes in the wooden end of the armature, lead the ends of the wires through them, so that each rests against the middle of one section of the brass ring. Bare the ends of the wire, and solder them to their respective sections.

File off the head of the $2''$ screw.

Screw the $1''$ screw *exactly* into the centre of the other wooden end of the armature to a depth of $\frac{1}{2}''$. File off the head of the screw.

NOTE.—*The more care you take to get the two screws exactly in line, the better your motor will run.*

4. **Brackets.**—Set out with a scriber the piece of $\frac{1}{16}''$ strip brass $3\frac{1}{2}'' \times \frac{3}{4}''$, as shown in Fig. 144.

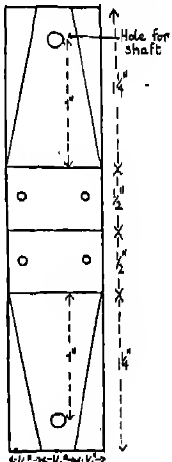


FIG. 144.

Drill holes as indicated, saw and file to the required shape, and split into two along the middle line.

Fix in a vice, and make a right-angled bend on each piece at the remaining scribed line.

5. **Brushes.**—Set out with scriber the two pieces of brass, $2\frac{1}{2}'' \times \frac{1}{2}''$, as shown in Fig. 145 (*a*).

Make right-angled bends as shown in (*b*), and brad or drill holes in positions marked. Bend the strip over at the end to act as a terminal.

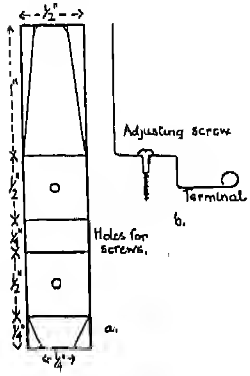


FIG. 145.

6. **Baseboard.**—Chamfer the piece of wood, $8'' \times 4\frac{1}{2}'' \times \frac{1}{2}''$, a $\frac{1}{4}''$ each way.

7. **Assembling the Parts.**—Screw the field magnet through the drilled holes across the middle of baseboard.

Place the armature in position between the poles of the magnet, mount the brackets on the filed screws as pivots, and screw the brackets to the baseboard.

Place the two brushes on opposite sides of the commutator, and just touching it. Screw the brushes to the baseboard. Place the adjusting screws through the remaining holes, and screw a little distance into the base. By screwing or unscrewing these, the contact of the brushes with the armature can be regulated.

Fix two terminals on the baseboard. Complete the connection by joining one wire from field magnet to a terminal, the other wire to a brush. The remaining brush should be connected by copper-wire to the second terminal. To work the model, connect the two terminals to the poles of the battery. (A dry battery of 3 or 4 volts or two bichromate cells should give good results.)

6. Electric Motor (Tripolar).

Material required:

1 piece soft strip iron, $8\frac{3}{4}'' \times \frac{5}{8}''$.
3 pieces tinplate, $1\frac{3}{4}'' \times \frac{1}{2}''$,

1 piece brass or copper tubing, from $\frac{1}{4}''$ to $\frac{3}{8}''$ bore, $\frac{1}{2}''$ long.
1 piece ebonite or hard wood rod to fit the metal tube.
1 ebonite or rubber washer to fit tightly over the tube.
1 piece $\frac{1}{16}''$ steel rod (or *stout* knitting-needle), $3\frac{1}{4}''$ long, for spindle.
2 pieces strip brass, $\frac{1}{16}'' \times 1\frac{1}{2}'' \times \frac{3}{4}''$.
2 ,, ,, ,, (No. 26 or 28 gauge), $\frac{1}{4}'' \times 1\frac{7}{8}''$.
1 piece of wood, $3'' \times 1'' \times 1''$ | for use as templates as construction.
2 wood cylinders, $1\frac{1}{4}''$ diam., $1''$ long

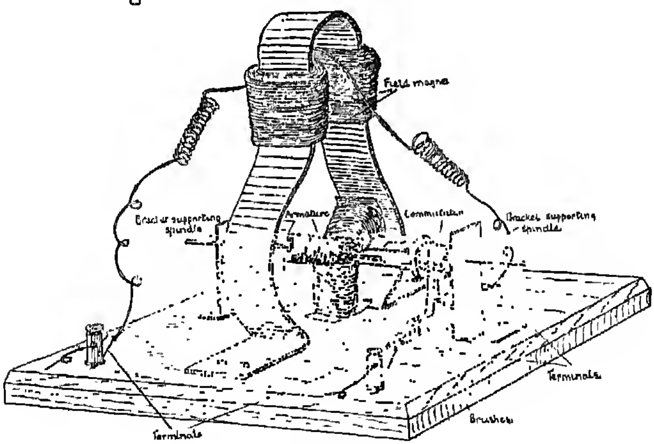


FIG. 146.

1. **Field Magnet.** — From the piece of wood, $3'' \times 1'' \times 1''$, construct the template shown in Fig. 147. Draw the circle on paper cut the segment out, and use it to draw the shape on the wood. Bowsaw and spokeshave to line,

Drill four holes at the ends of the iron strip to take

$\frac{1}{2}''$ screws, lay it along the block so that one end of the strip is flush with the end *A* and screw it down to keep it

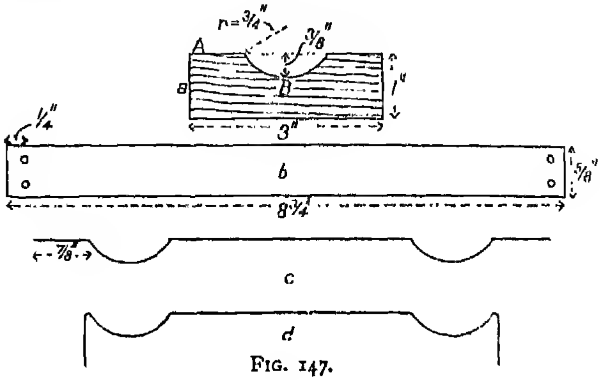


FIG. 147.

in position while it is hammered to the shape of the template with a hammer and one of the wooden cylinders.

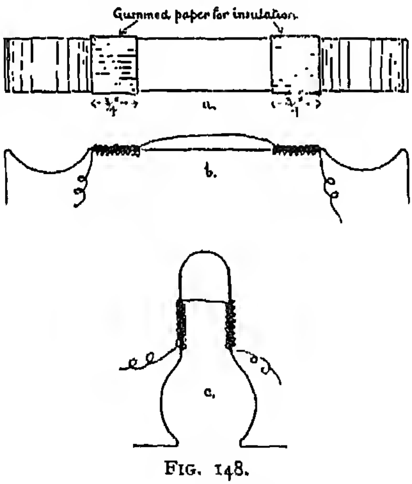


FIG. 148.

Unscrew the iron strip, reverse the ends, and repeat the process. The strip is now the shape shown in

Fig. 147 (c). Bend the ends at right angles to the length [see Fig. 147 (d)]. Insulate the middle portion for a distance of $\frac{3}{4}''$ from each bend, and wind five layers of No. 22 or 24 D.C.C. wire on each portion. Leave about 5″ of free wire at each end [Fig. 148 (a) and (b)]. Fasten securely with thread and glue.

Place the strip, when dry, with its centre line across an iron rod, $\frac{1}{2}''$ to $\frac{3}{4}''$ diam., held in a vice, and bend, bringing the ends towards each other until the magnet is shaped as in Fig. 148 (c).

The Armature.—Take the second wooden cylinder ($1\frac{1}{4}''$ diam., 1″ long), draw two radii at an angle of 120° on one end, and cut out the wedge shown in Fig. 149 (a).

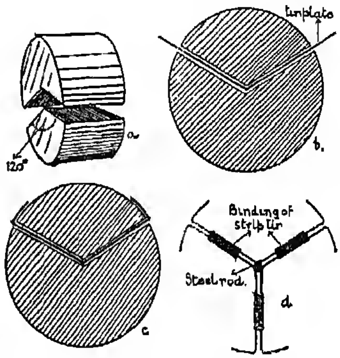


Fig. 149.

Place the piece of tinplate, $1\frac{3}{4}'' \times \frac{1}{2}''$, across the angle of the larger piece and press it into shape by hammering the small piece back into its position before cutting. Tap the projecting ends over the curved surface of the wedge, as shown in Fig. 149 (b) and (c). Repeat this with the remaining pieces of tinplate.

Place the three pieces together, as in Fig. 149 (d), and bind tightly and securely with a narrow strip of tinplate. Force the steel rod for the shaft through the centre until it projects about $\frac{7}{8}''$ on the other side.

Hold the armature thus formed by means of pliers, heat the junction of the rod and tinplate strongly in the Bunsen flame, apply a little flux, dip a rod of

solder in flux and rub it around the hot junction until a strong joint is obtained.

NOTE.—*By this method the hot solder runs down the groove between the shaft and the tinplate.*

Insulate the arms, when cool, with binding cloth or gummed paper, and bind six layers of No. 24 or 26 insulated copper wire carefully round one of them. Leaving a length of about 2″ for connecting, proceed to wind the next arm. To do this, hold this second arm in exactly the same way as the first, and then wind the wire *in the same direction* as the first. Do the same with the third.

Fig. 150 indicates the direction of winding and the manner of leaving a loop for attaching wire to commutator. Only one turn of wire has been shown on each arm.

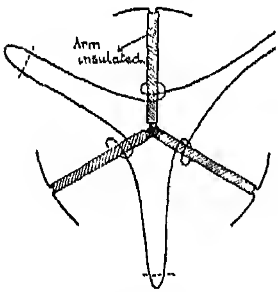


FIG. 150.

The loops should be cut across at the places indicated by the dotted lines, the ends bared and twisted together ready for attaching to the commutator.

The Commutator.—File the ebonite or hard wood cylinder until it exactly fits the copper or brass tube. Give the ebonite a coat of glue, slip the tube over it, and bore a hole through the centre of the ebonite just sufficiently large to permit it to be forced on the shaft. With a fine saw carefully divide the tube lengthways into *three* equal parts.

Solder one of the twisted armature wire ends to each section of the commutator, and slip the ebonite or rubber washer over the commutator to keep the sections

from moving. You will understand this if you look at Fig. 146.

Brackets and Brushes.—Set out, cut, and bend these, according to the dimensions given in Fig. 151 (*a*) and (*b*).

Directions for carrying this out and for assembling the parts are given in the previous model.

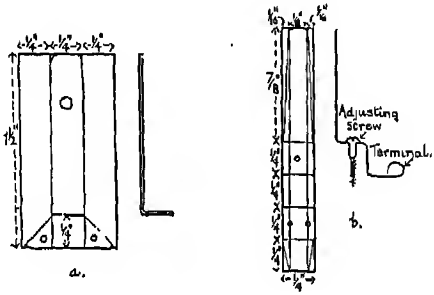


FIG. 151.

Connect the wires as before.

The motor should work with an ordinary dry battery of 3 or 4 volts.

NOTE.—*To prevent the shaft from moving from its position in the brackets, two collars can be constructed by boring suitable holes in small pieces of brass rod and forcing them along the shaft into position. Meccano spring clips will do equally well.*

7. Coil Winder.

Material required:

1 piece wood, $6'' \times 3'' \times \frac{1}{2}''$—baseboard.
2 pieces of wood, $3'' \times 1'' \times \frac{1}{2}''$—uprights.
1 piece $\frac{1}{8}''$ mild steel rod $9''$ long—spindle.
1 Meccano faceplate.
1 Meccano collar.

NOTE.—*These parts can be bought separately in any shop supplying Meccano outfits.*

Cramp the two pieces, 3″ × 1″ × ½, with the face sides exactly together.

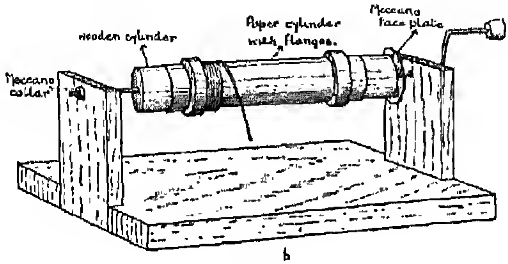


FIG. 152.

On the middle line ¼″ from one of the 1″ ends drill a ⅛″ hole through both.

Halve the other ends of the uprights and lap them

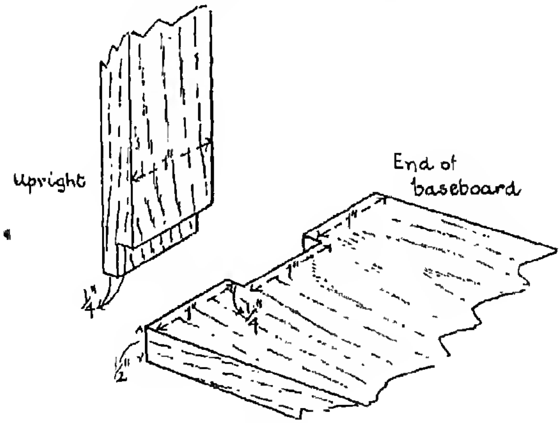


FIG 153.

into 3″ edges of the baseboard, accurately in the middle (see Fig. 153).

Glue and brad.

To form the handle of the spindle make a right-angle bend in the rod 7″ from one end, and 1″ farther on another right-angle bend, bringing that last inch of the rod back in the same direction as the 7″ portion.

File the last ¼″ at the handle end to a square taper. A little wooden cylinder bored and tapped on to this point will form a handle.

Put one Meccano collar on the spindle and push the the spindle through the hole in one upright.

Slip the faceplate on, and push through the other hole.

Add another collar beyond the upright, and, allowing a little play, screw the setscrews up until they grip the spindle.

NOTE.—*A set of drilled wooden cylinders will be required. These should be prepared in various diameters. The drilling will present difficulties, but with a little ingenuity a boy should be able to make a "fence" (or guide) to ensure that he is boring along the axis of the cylinder.*

To fix a cylinder, the collar farther from the handle is taken off, and the spindle pulled from one upright. A wooden cylinder with a prepared paper cylinder (Fig. 152) attached is slipped on tbe spindle which is then readjusted.

The Meccano faceplate is then screwed to the circular end of the cylinder, and the setscrew tightened.

NOTE.—*The holes for the spindle* **must not be more than ¼″** *from the* **top of each upright**—*otherwise it will be difficult to screw the cylinder to the faceplate.*

8. Telephone Receiver.

Material required:

1 piece wood, $7\frac{1}{2}'' \times 2\frac{1}{4}'' \times \frac{1}{2}''$.
1 ,, ,, $2\frac{1}{4}'' \times 2\frac{1}{4}'' \times \frac{1}{4}''$.
2 pieces tin, $5'' \times \frac{1}{2}''$.

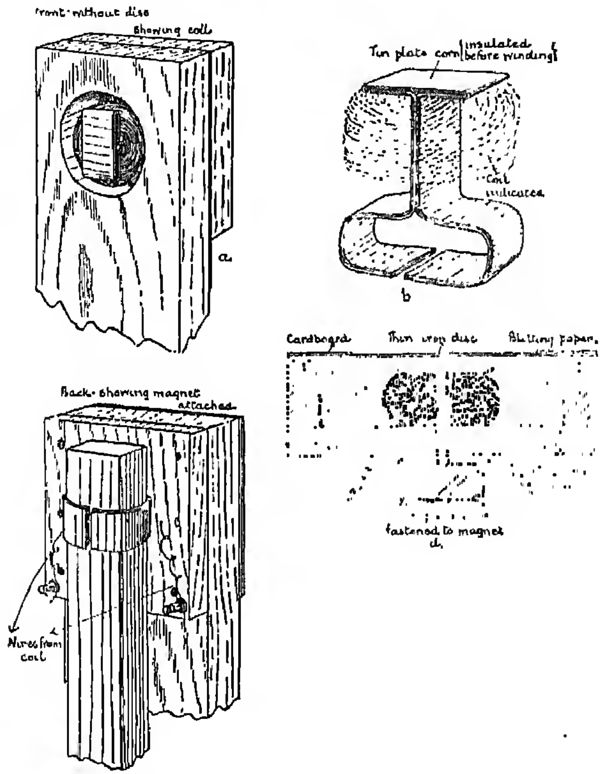


Fig. 154.

1 piece ferrotype, $2\frac{1}{4}'' \times 2\frac{1}{4}''$.
1 ,, blotting paper, $2\frac{1}{4}'' \times 2\frac{1}{4}''$.
1 ,, cardboard, $2\frac{1}{4}'' \times 2\frac{1}{4}''$.
Reel of fine insulated wire (No. 36).

$\frac{1}{4}''$ and $\frac{3}{8}''$ screws.

1 bar magnet (assumed to be $6'' \times \frac{3}{4}'' \times \frac{3}{8}''$).

2 terminals.

Cut a slot $\frac{1}{2}''$ long in the middle of the piece of wood $2\frac{1}{4}''$ square in the position shown in Fig. 155 (*a*). This can be done with a bowsaw or a keyhole saw.

Double the two pieces of tin, held exactly together, in halves, and push them through the hole, so that the

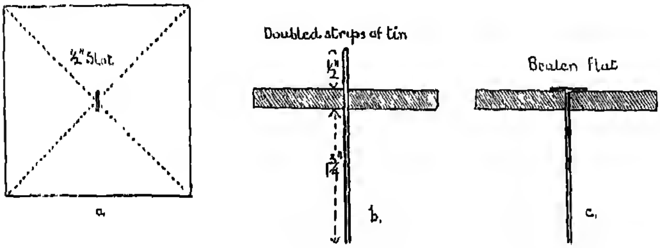


FIG. 155.

doubled end projects exactly half an inch (Fig. 155, *b*). The slot should be of such a width that the tin remains firmly in position.

Grip the pieces projecting on the otherside in a vice, so that the wooden square rests on the jaws. Prise the double ends apart with a small screwdriver, and tap them down flat until the tin is shaped like a paper-fastener (Fig. 155, *c*).

NOTE.—*Be careful not to split the wood.*

In the piece of wood, $7\frac{1}{2}'' \times 2\frac{1}{4}'' \times \frac{1}{2}''$, bore a hole $1''$ diameter, with its centre on the middle line $1\frac{1}{8}''$ from one end.

Place the wood down on a flat portion of the bench and rest the wooden square on it, so that the paper-fastener head is downward and over the hole.

Push the strips of tin through the slot in the wood

until the "paper-fastener" end rests on the bench. Then bend each double strand outwards and tap flat.

Prepare an odd strip of wood to the exact dimensions of the magnet. Place this strip across the double strands, and bend the tin round it, tapping it down to the exact shape with a hammer.

NOTE.—*A strip of wood is used, as it is not wise to hammer a magnet.*

Thoroughly insulate the head and shaft of the tin projecting on the other side, and wind as many turns of the wire around it as possible.

Make two holes through the wood just large enough for the free wires from the coil to be pushed through.

NOTE.—*Before winding, the wire should be dipped in melted paraffin-wax and allowed to drain.*

Cut holes 1¼" diameter exactly in the centres of the blotting-paper and the cardboard.

Assembling the Parts.—Screw the two pieces of wood together, so that the head of the electromagnet rests in the centre of the hole.

Replace the piece of wood held by the tin with the magnet. Push the wires through the holes.

Place the blotting-paper over the hole, the ferrotype disc exactly over the blotting-paper and the cardboard on the disc.

Drill and screw to the wood with ¼" screws.

The ferrotype disc should now be the thickness of a piece of blotting paper from the head of the magnet.

Fix the two terminals, as in Fig. 154, and attach wires.

9. Telephone Transmitter or Microphone.

Material required:

1 piece wood, 3½" × 3½" × ½".
2 pieces of wood, 3½" × ½" × ½".
1 piece thick cardboard, 2¾" square.
1 ,, felt or flannel, 2¾" square.
1 ,, ferrotype, 2¾" square.
1 ,, tinplate, 1⅜" square.
1 ,, blotting-paper, 1⅜" square.
2 short lengths of insulated copper wire.
¼" and ⅜" screws.
Carbon granules (made by powdering pieces of carbon from an arc-lamp—or even coke).

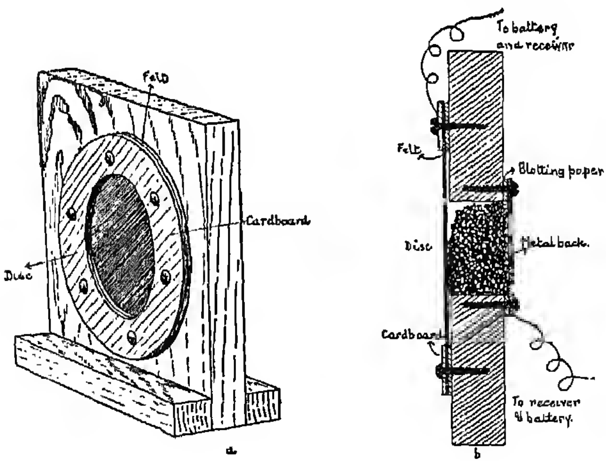


FIG. 156.

Cut from—

(1) The thick cardboard, } a ring, outside diam. 2¾",
(2) The felt or flannel, } inside diam. 1¼".
(3) The ferrotype, a disc of 2¾ diam.

(4) The blotting-paper, a ring, outside diam. $1\frac{3}{8}''$, inside diam. $\frac{7}{8}''$.

(5) The tinplate, a disc of $1\frac{3}{4}''$ diam.

Draw the diagonals on the piece of wood $3\frac{1}{2}''$ square, and at the middle point bore a $\frac{7}{8}''$ diam. hole.

Drill four holes round the tinplate disc $\frac{1}{8}''$ from the edge.

Place the ring of blotting-paper on the wood, so that it fits the $\frac{7}{8}''$ hole, place the tinplate exactly over it, and screw to the wood.

Turn the wood over and place enough carbon granules in the cavity to fill about three-quarters of the space.

Clean one side of the ferrotype free from varnish, and drill six holes around it $\frac{1}{8}''$ from the edge.

Place the ring of felt on the wood, so that the circles have the same centre as the hole.

Place the ferrotype disc on this and the cardboard on the disc. Screw to the wood.

Bare the ends of the wires and scrape clean. Attach one wire with its end firmly under a screw head on one side, and the other similarly on the other side.

Glue the two strips, $3\frac{1}{2}'' \times \frac{1}{2} \times \frac{1}{2}''$, one to each side, as in Fig. 156, to form a stand.

A mouthpiece can be attached, if desired. It is not necessary to the successful working of the model, although an improved effect can be obtained with it.

10. Shocking Coil.

Material required:

1 piece of wood,	$10'' \times 4'' \times \frac{1}{2}''$	(baseboard).
1 ,, ,,	$3\frac{1}{4}'' \times 2'' \times \frac{1}{2}''$	(upright).
1 ,, ,,	$3'' \times 2'' \times \frac{1}{2}''$	,,
1 ,, ,,	$8'' \times 2\frac{1}{2}'' \times \frac{1}{2}''$	(slide).

1 piece of wood, $1\frac{1}{2}'' \times \frac{3}{4}'' \times \frac{1}{2}''$ (slide).
1 " " $3'' \times \frac{3}{4}'' \times \frac{1}{2}''$ (upright for interrupter).
1 wooden disc, 1″ diam., about $\frac{1}{4}''$ thick,
1 piece (thin) tinplate, $9'' \times 4\frac{1}{4}''$.
1 " sheet brass, $3\frac{1}{2}'' \times \frac{1}{4}''$.
1 dresser hook.
2 soft iron discs, $\frac{1}{2}''$ diam.
2 terminals.
2 coils—one wound with stout wire on a cylinder $\frac{1}{2}''$ diam., 4″ long; one wound with fine wire on a cylinder, 1″ diam., 4″ long.

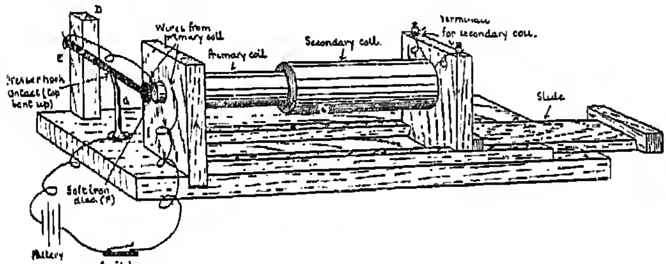


FIG. 157.

Coils.—General instructions on the preparation and winding of the primary and secondary coils are given Chapter XXVIII. For the model here described, the

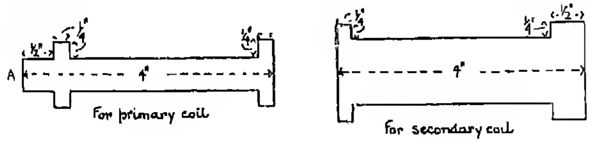


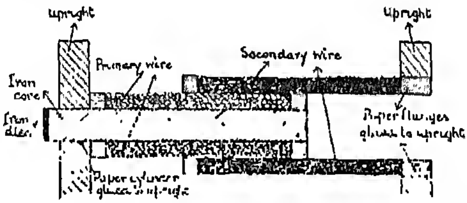
FIG. 158.

position and size of the flanges of the paper cylinders have been slightly altered. This can be followed from the diagram, Fig. 158.

NOTE.—*Take every care to ensure that the wire is thoroughly insulated, particularly with regard to the secondary coil. Not only should the wire be dipped in melted paraffin wax and drained before winding, but a sheet of thin, waxed paper may be placed between each layer of wire. When winding, begin and finish at the same end of the coil. Leave two or three inches free for connections.*

Core.—Roll the piece of tinplate around a lead-pencil or penholder until it forms a tightly-rolled cylinder, 4¼″ long, and not more than ½″ diam. This will form the **Core.** File one end of this perfectly flat, and solder one of the ½″ iron discs to it. (Fit it accurately on the end.)

Slip the core into the primary coil until the soft iron disc protrudes ¼″ from the end, marked *A* in Fig. 158. The core should fit well; if it does not, wrap some



Section through Coils

FIG. 159.

gummed paper round it until it will not move easily from its position.

The positions of the two coils and the core with regard to the uprights can be followed from the section shown in Fig. 159.

Baseboard.—Prepare the baseboard according to the dimensions given in Fig. 160, and cut the slot and groove as shown.

Slide.—Two sections of the slide are given in Fig. 161 (*a*) and (*b*). Set out on the end of the piece of

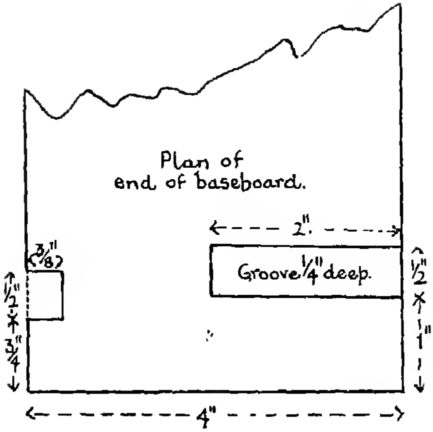


FIG. 160.

wood $8'' \times 2\frac{1}{2}'' \times \frac{1}{2}''$ the dimensions given in (*a*). Pencil gauge the lines along each $8'' \times 2\frac{1}{2}''$ surface and cut into three pieces.

Plane the sawn surfaces, leaving the finished dovetail of the dimensions given in (*b*).

Set out and cut the piece of wood $1\frac{1}{2}'' \times \frac{3}{4}'' \times \frac{1}{2}''$ according to directions given in (*c*).

Reduce the length of the runner, the middle piece in (*b*), to $4\frac{1}{2}''$, and glue and brad the piece of wood cut, as in (*c*), on one end. (Don't throw away the $3\frac{1}{2}''$ piece cut off.)

Uprights.—Set out the two pieces of wood, $3\frac{1}{4}'' \times 2'' \times \frac{1}{2}''$ and $3'' \times 2'' \times \frac{1}{2}''$, according to the dimensions given in

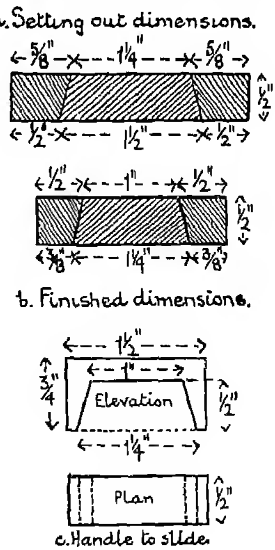


FIG. 161.

Fig. 162 (*a*) and (*b*). Cut the joints and chamfers and bore the holes. Glue and brad (*a*) into the groove in the baseboard.

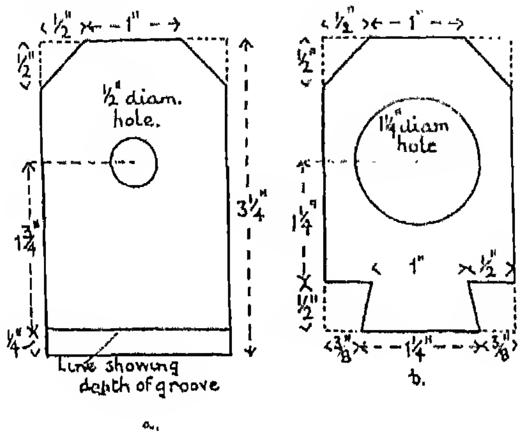


FIG. 162.

NOTE.—*Test frequently while doing this, by placing trysquare upright on baseboard against the piece of wood.*

Fit the other piece (*b*) upright against the end of the runner (dovetails coinciding exactly); glue and brad in this position, the two brads sloping inwards, as in Fig. 144, p. 182, Book I.

NOTE.—*In* Fig. 157 *a support is shown behind the upright. This can easily be fitted, if necessary, but is not included in these instructions.*

Place the two outside pieces of the slide on the baseboard with their ends against the uprights, one being flush with the side of the baseboard. Fit the runner and the piece cut off in between, and pinch together, so that they fit accurately, and the slide moves smoothly. Glue and screw the outside pieces to the baseboard in

this position. (The waste piece of runner can then be removed.)

Glue the prepared end of the secondary coil into the $1\frac{1}{4}''$ hole, first pushing the $1''$ diameter wooden disc in the end, to prevent the paper cylinder from breaking.

Glue the end of the primary coil into the $\frac{1}{2}''$ hole in the upright, so that the soft iron disc projects $\frac{1}{4}''$ beyond the hole.

NOTE.—*The $\frac{1}{2}''$ hole may require a little "easing" with a half-round file, but a tight fit is necessary.*

Push the slide in so that the secondary coil fits over the primary, and leave to dry.

Interrupter.—Halve $\frac{1}{2}''$ at one end of the other upright $3'' \times \frac{3}{4}'' \times \frac{1}{2}''$, and glue and brad into the other slot in the baseboard shown in Fig. 160.

Drill two holes in the piece of brass $3\frac{1}{2}'' \times \frac{1}{4}''$—one $\frac{1}{2}''$ and the other $\frac{3}{4}''$ from one end.

Beat the strip well with a mallet to render it springy, and twist up the last $\frac{1}{4}''$ at the end where the holes are drilled to form a terminal.

Place the strip with the terminal end against the upright $1\frac{3}{4}''$ above the baseboard (see Fig. 157).

The other end of the strip should rest exactly across the protruding iron disc on the primary coil.

If this is not quite so, mark the position of the disc on the strip and solder the other iron disc accurately on this spot, so that the two discs will touch exactly when the strip is fixed in position.

Screw the strip to the upright.

Now bend the strip backwards a little, so that the two discs are about $\frac{1}{16}''$ apart.

Force the bent end of the dresser-hook upwards. and screw it into the baseboard (see Fig. 157) in such a

position that, when it is turned, it will touch the brass strip and bring the two soft iron discs very close to each other.

NOTE.—*If the hook is not long enough, raise it with a block of wood.*

The coils should now be dry. Pull the slide out a little way, and with a fine bradawl make two holes through the upright holding the primary coil, opposite the free ends of the wire. Push the wires through these holes, and connect up as in Fig. 157.

Screw the two terminals in the top of the slide upright, and connect the secondary wires with them.

These terminals must also be connected by wires with two pieces of brass tubing about 3″ long.

When in use, move the slide gently.

11. Model showing Change of Motion.

Material required:

1 piece stiff cardboard, 6″ × 9½″.
1 large paper-fastener.
A few eyelets and an eyelet punch.
Cold glue.

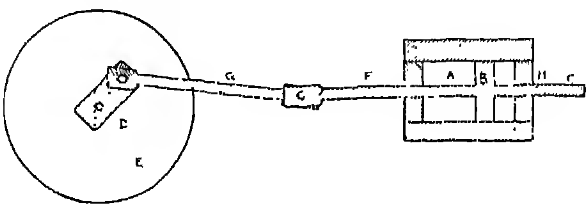


FIG. 163.

Carefully set out and cut the pieces according to the dimensions given in Fig. 164.

NOTE.—*This will require care. The waste is shaded.*

The holes punched for eyelets in the parts *D* and *G* are $\frac{1}{4}''$ from the end of the cardboard in each case.

F and *D* are fixed underneath the two ends of *G* with

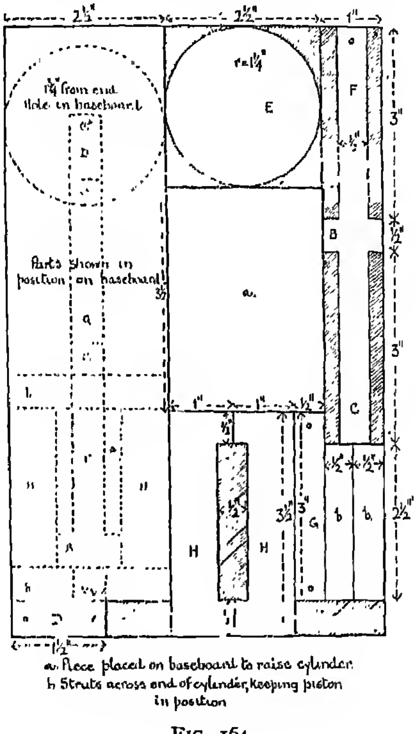


FIG. 164.

eyelets. Fasten them tightly, and then rotate the pieces until they move freely.

In *D* and *E* a slit will be noticed, and not a hole. The crank *D* is placed on the flywheel *E*, and the paper-fastener is pushed through both slits. It is then pushed through the hole in the baseboard (see Fig. 164), and the ends bent outwards underneath.

This allows the wheel to turn on the baseboard, but the crank must turn with it.

The part marked *a* is fitted exactly on the other end of the baseboard and glued in this position.

Place on this the two parts marked *H*, in the same position as they are in Fig. 164, but moved apart $\frac{1}{2}''$. The $3''$ sides will then lie exactly along the long sides of the baseboard.

Place the piston-rod in the cylinder.

The two parts *b* are glued at each end only, and placed across the ends of the parts *H* to prevent the piston rod from slipping out.

NOTE.—*You will find that in two positions of the piston, the farthest forward and the farthest back, the model will not work. These are called the "dead ends," and in an engine the weight of the revolving fly-wheel would carry it past these points. You must assist it, as your fly-wheel is not heavy.*

12. Model showing Principle of Single-Acting Oscillating Cylinder.

Material required :

1 piece stiff cardboard, $3''$ square.
1 " " " $5\frac{1}{2} \times 1\frac{1}{2}''$.
1 large paper-fastener.

Set out and cut the cardboard, according to the dimensions given in Fig. 166.

The parts shaded in one direction only are waste. The two circles shaded in two directions are to be coloured blue and red, as shown.

Place the piece $5'' \times 1\frac{1}{2}''$ on the square, so that the hole *A* is exactly over the slit *B*.

Fasten through *A* and *B* securely with a paper-

fastener. The top piece should then be free to rotate on the bottom piece.

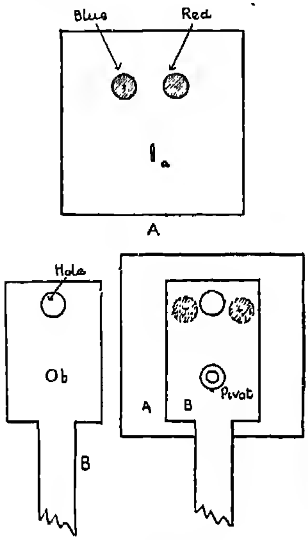


FIG. 165.

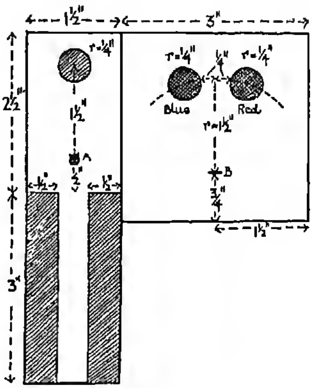


FIG. 166.

13. Model showing Principle of Double-Acting Oscillating Cylinder.

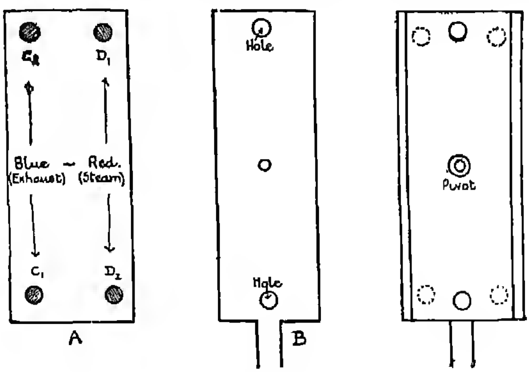


FIG. 167.

Material required:

1 piece stiff cardboard, $4\frac{1}{2}'' \times 3''$.
1 " " " $6'' \times 1\frac{1}{2}''$.
1 large paper-fastener.

Set out and cut according to the dimensions given in Fig. 168. Follow the directions for Model 12.

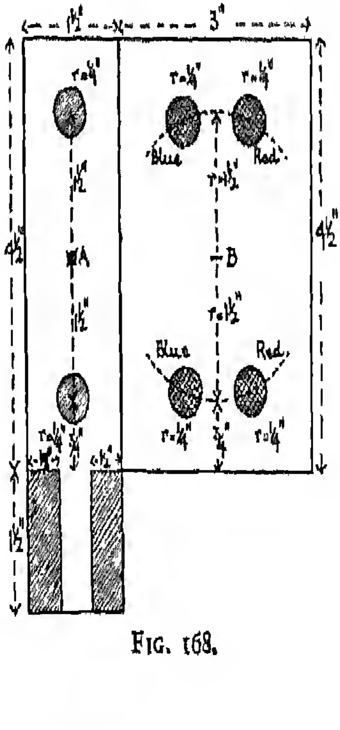


FIG. 168.

APPENDIX

BOYLE'S LAW.

A PIECE of apparatus frequently adopted for showing the relationship between the pressure and volume of a gas is shown in Fig. 169. The gas to be used (usually air) is enclosed in the small tube AB fixed to the stand. This tube is connected by a length of rubber-tubing to another tube CD, which can slide up and down beside a vertical scale. (The rubber-tube must be fastened as strongly as possible to the glass tubes.) A method of arranging the slide is shown in section. A small clamp can be used to hold the slide at any desired height. Mercury is introduced into the tube until a column of air about 6″ long is left in AB, when the mercury in each tube is at the same level. This enclosed air will now be at atmospheric pressure, which can be ascertained by reading the barometer. Mark the level of the mercury in AB.

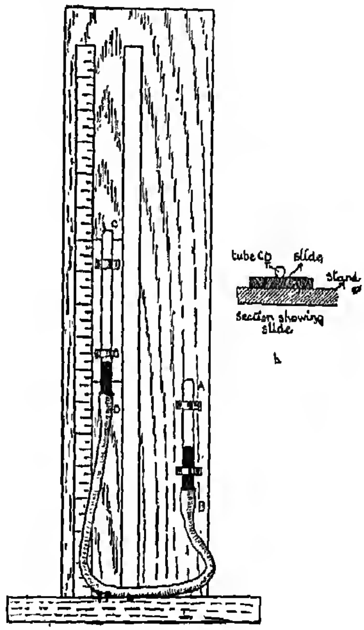


FIG. 169.

Move the sliding piece upwards several inches. The mercury in the sliding tube will stand higher than the mercury in the fixed tube; but the mercury in the latter

will also have risen to a certain extent, because there is now a greater pressure on the enclosed air. The actual value of this pressure can be measured by adding the difference of the two levels of mercury to the barometric reading as explained in Chapter V.

Move the sliding tube to its lowest position. The mercury in this tube is now lower than in the other, although the mercury in *AB* has also fallen. The pressure of the enclosed air is now *less* than atmospheric pressure. Its value can be ascertained by *subtracting* the difference in the levels from the barometric reading.

By taking several results, a table similar to that on p. 37 can be drawn up.

PRESSURE OF GAS IN THE GAS-PIPES.

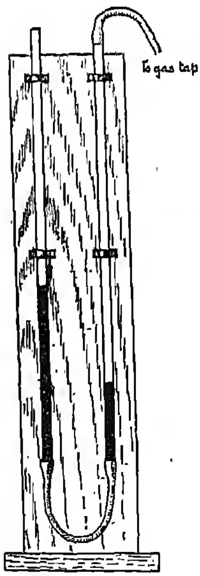


FIG. 170.

The apparatus needed to carry out the measurement of the pressure of gas in gas-pipes is indicated in Fig. 170. It consists of a U-tube, open at each end, mounted on a suitable stand, and containing sufficient water or mercury to cover the bend. A rubber-tube is attached to one limb of the U-tube and to a gas-tap. *Before* the gas is turned on, the levels of the water or mercury should be the same in each limb, but *after* the gas is turned on, the liquid in the open limb rises, showing that the pressure of the gas is greater than that of the atmosphere. The amount of this pressure can be measured as in previous experiments. (In speaking of gas pressure, it is usual to neglect the atmospheric pressure and to state only the amount by which the pressure of

the gas exceeds the pressure of the atmosphere. As this is not very great, it is generally expressed as being equal to so many inches of water instead of mercury.)

PRESSURE OF WATER IN THE WATER PIPES.

An open U-tube cannot be used for this experiment, as the pressure would cause the water to overflow, but a closed tube gauge such as was used for Boyle's Law will prove suitable for the purpose. Fix up the tube as shown in Fig. 27, and mark the height of the mercury in each limb. Fill the long limb to the top with water, and then by means of a stout piece of rubber-tubing attach the limb to a water-tap. (The rubber-tubing must be securely fastened by wire or other means, or the pressure will force it off.)

When the water is turned on, the increased pressure will drive the mercury up the shorter limb until the pressure of the enclosed air equals that of the water.

To find the value of this pressure, we must use our knowledge of Boyle's Law. Measure the length of the air columns before and after turning on the water. Since the product of the volume and pressure of the enclosed air remain constant, then

New pressure × new volume = first pressure × first volume.

The first pressure of the enclosed air was that of the outside air, and can be ascertained from the barometer; the volumes of the enclosed air can be compared by comparing the lengths of the columns (see note on p. 36).

Therefore we have—

New pressure × 2nd length of air column
= barometric reading × 1st length of air column,

from which the new pressure in inches of mercury can be calculated. The value we thus obtain represents the pressure

of the air *increased* by that due to the water-supply. If we subtract, therefore, the barometric reading from this value, we can find the acting pressure of the water in inches of mercury. To find what pressure head of water this is equivalent to, the result should be multiplied by 13·5. (This experiment should only be attempted when the supply is from a cistern. The result should be confirmed by measuring approximately the height of the tank above the experimenter's bench.)

SOUND RANGING.

Since sound travels normally at the rate of 1090 feet per second, and light travels at such a rate that the flash of an explosion is seen by an observer at practically the instant it takes place, it is quite an easy matter to calculate the distance of a hostile battery if the flash can be seen, and an accurate measurement of the interval between the flash and the report can be made. If, for instance, the flash of a gun is seen 8·7 seconds before the report is heard, the distance of the gun from the observer must be

1090 feet $\times$ 8·7 = 9483 feet = 3161 yards = 1 mile 1401 yards

But is it possible to estimate the distance of a hostile battery when the flash can *not* be seen—that is, by sound only? Yes; but in this case more than one observation station is needed.

Suppose that A and B are two observation stations, and that both are electrically connected to a receiving station. At the instant each hears the report to be registered a message is flashed to the receiving station, where by a special apparatus differences of time can be registered to the hundredth part of a second. Suppose that A hears a report four seconds later than B, then A must be 1090 $\times$ 4 feet farther from the gun than B.

Now study the diagram of Fig. 171 (*a*). (To use a scale suitable for such a small drawing, 1090 feet $= \frac{1}{10}''$.) The points *D*, *E*, and *F* are all $\frac{4}{10}''$ farther from *A* than *B*, and we can see that there are an infinite number of such points, but *they all lie along the dotted curve or its continuation.*

If, then, a *third* observation station, *C*, hears the report five seconds after *A*, we can construct *another curve*, every

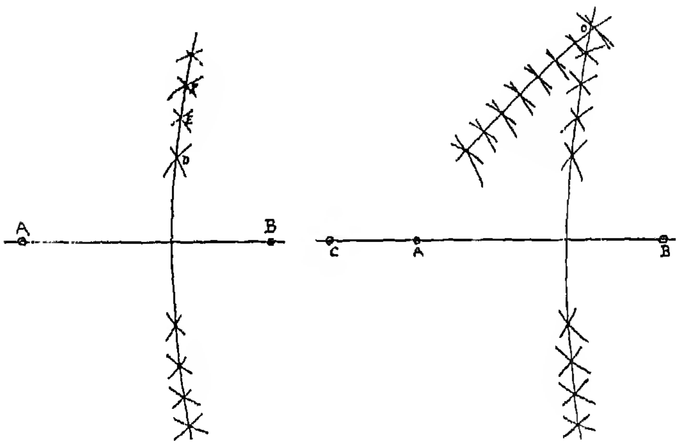


FIG. 171.

point on which is $\frac{5}{10}''$ further from *C* than from *A* [Fig. 171 (*b*)].

It is clear, then, that *O*, the intersection of the curves, represents the position of the source of sound.

One point concerning the recording of the exact moment a sound is heard should be noted. With some observers the time between the hearing of a sound and the pressing of a button is greater than in others, and an apparatus called a "sound-detector" has been invented, which automatically sends the signal to the central station at the exact instant the apparatus receives the sound-waves.

THE SOLAR SPECTRUM.

In Chapter XIV. it was shown how the white light of the sun or a gas-flame could be broken up into a band of colours, ranging from red at one end to violet at the other. This band of colours was called a spectrum.

Light is really a series of minute waves which are sent out from the luminous body through the ether of space. These waves are not all of the same length, but *all* of them are very small—much less than the ten-thousandth part of an inch measuring from one wave-crest to the next. Each wave-length corresponds to a certain definite colour, the shortest giving us a violet, the longest a red, colour. When these rays are passed through a glass prism they are refracted to different extents, the red least, the violet most.

Pure white light is composed of rays of *all* the different lengths from the red to the violet, and consequently a continuous spectrum can be obtained by interposing a prism in its path.

Now any substance that is made hot enough to become incandescent will form a spectrum. It may not be a continuous band like that of white light, but it will give lines of colour that are constant for the elements that make up the substance. The metal sodium, for example, will combine with many other elements; but whenever a compound of sodium is heated in the non-luminous flame of a Bunsen-burner and a spectrum obtained, certain bright yellow lines will always be found in exactly the same place in the spectrum. Any potassium salt treated in the same way gives three bright lines near the red end, a broad portion in the yellow and blue section, and one line far away towards the violet end. Every metal has its own distinctive lines of colour in the spectrum.

Here is one method by which we can identify the

presence of a metal in a substance. The substance can be raised to incandescence and the spectrum examined. The substances need not be heated, however, in our Bunsen-burners to be detected in this way. They may be in a state of incandescence in a distant star. By obtaining a spectrum and carefully comparing it with the spectra of known metals, the presence of certain substances on the distant star can be affirmed with certainty.

But another interesting fact has been discovered—that light, passing through a medium such as a gas, is to a certain extent absorbed by it. Further, the kind of rays absorbed are those the gas would itself give out if it were incandescent. Thus if white light from a very hot body, such as the electric arc, is passed through sodium vapour and a spectrum obtained, two *dark* bands are found in the orange-yellow part. If the spectrum of a sodium salt alone is taken, the same positions will be occupied by two *bright* lines.

Now, if the spectrum obtained from a ray of sunlight is carefully examined, it will be found that it is not continuous, but crossed by a great many dark lines. The white-hot nucleus of the sun sends out rays of *all* wave-lengths, but some of these are absorbed by the cooler vapours surrounding it, and these absorption lines are found in the spectrum. We know that sodium is present in the sun's atmosphere because of the two dark lines in the orange-yellow described above. Most of the elements found on the earth have been shown to exist in the sun. Until a few years ago certain lines in the solar spectrum did not agree with those of any element we knew on the earth, and the existence of an element new to us was assumed. It was named *helium*, from the Greek *helios*, the sun. Many years after it was thus named, a gas was discovered in certain minerals by Sir William Ramsay which gave the same spectrum as helium. Here we have a case of an element recognized on the sun before it was known on the earth.

STORAGE BATTERIES OR ACCUMULATORS.

In studying the action of a simple cell (see Book II., Chapter VII.), it was found that when the circuit was completed a current flowed, but rapidly decreased owing to a film of hydrogen forming on the copper plate. This is termed polarization. This film not only resists the passage of the current because it is a non-conductor, but sets up an electromotive force in the opposite direction to that of the current.

A similar electromotive force opposing the action of the current is set up during the electrolysis of water. One of the best arrangements to show this is known as Grove's gas battery, in which the electrodes are of platinum, and occupy nearly the whole length of the tubes (see Fig. 172).

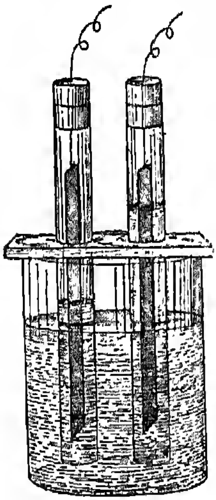


Fig. 172.

The tubes are filled with water (with the addition of a little sulphuric acid), and a current passed as in Experiment 82, Book II., until the hydrogen tube is filled. The battery is then disconnected, and the electrodes joined to the terminals of a current detector or an electric bell. A current flows in the circuit for some time, shown by the movement of the magnetic needle or the ringing of the bell. This current can be shown to be in a *reverse* direction to that which caused the breaking up of the water. The gases gradually disappear, water rises in the tubes, and the current continues until the latter are filled again.

This principle is used in the construction of what are termed **secondary cells** or **accumulators**—that is, cells through

which a current is first passed to produce electrolysis and which can then be used to give back a current, but in the reverse direction. These cells may be joined together to produce **storage batteries.** (The use of such storage cells is very clear. They can be "charged" at some central station where electric current can be cheaply and easily produced. Each cell thus charged is then a store of electrical energy which is very convenient for taking to any place where electric current is required. A storage cell is a device for distributing electricity in an economical and handy way.)

The usual form of a storage cell consists of two lead grids placed in dilute sulphuric acid, but also in most of them the hollows are filled with a paste of red lead and sulphuric acid, which mostly unite to form lead sulphate. The plates are joined by copper wires to the poles of a dynamo or other source of electricity, and a current of sufficient strength passed through the cell. The latter has received the maximum charge which it can hold when hydrogen and oxygen begin to be evolved freely at the electrodes. The current is then cut off, and the cell is ready for use—that is, if the lead plates are now attached to some apparatus such as an electric bell it can be made to do work.

The chemical changes that take place during charging are mainly the formation of lead peroxide on one plate and the reduction of the paste on the other to metallic lead. When the cell is being discharged again, the plates revert to their original state.

The E.M.F. of such a storage cell is just over 2 volts, but they are often joined in series, forming batteries to give 4, 6, or more volts. As the discharge takes place, the E.M.F. decreases, but it should not be allowed to fall below 1·8 volts for each cell in the battery. The accumulator should also not remain discharged for any considerable period.

The capacity of an accumulator is usually expressed in ampère-hours. This gives the number of hours the battery will work if the strength of the current is one ampère. For a greater or less current used, the hours will be proportionately shortened or lengthened. The capacity of an accumulator depends largely on the extent of the surface of the plates.

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